MINNESOTA DEPARTMENT OF TRANSPORTATION

# Traffic Impacts of Bicycle Facilities

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Research Project
Final Report 2017-23

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# Traffic Impacts of Bicycle Facilities

# FINAL REPORT

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# EXECUTIVE SUMMARY

Traffic Impacts of Bicycle Facilities is a research project funded by the Minnesota Department of Transportation (MnDOT) and the Local Road Research Board (LRRB) to inform the design of multimodal transportation facilities. The project involved a review of design guidelines for bicycle facilities, observation of bicycle-vehicle interactions at nine roadways in Minnesota with different types of bicycle facilities, analysis of results, and description of implications for design. The field observations involved review of video recordings and documenting driver behaviors while interacting with cyclists. The types of bicycle facilities that were observed included buffered bicycle lanes, striped bicycle lanes, sharrows, signed shared lanes, and shoulders of various widths. Driver behaviors were categorized as no change in trajectory, deviation within lane, encroachment into adjacent lane, completion of a full passing maneuver, and queuing behind cyclists.

The results show generally that drivers are less likely to alter their trajectories and deviate from their positions in the travel lanes or queue behind cyclists when facilities are clearly demarcated (Table ES-1). Across the nine locations, drivers on roadways with bicycle lanes (buffered or striped) were less likely to encroach into adjacent lanes, pass, or queue when interacting with cyclists than drivers on roadways with sharrows, signs designating shared lanes, or no bicycle facilities. Queueing behind cyclists, the most significant impact on vehicular traffic flows, generally was highest on roads with no facilities or shared facilities without marked lanes. The results also show that variation within and across types of facilities and that the outcomes of interactions on specific types of facilities cannot be presumed to be the same. Statistical modeling confirmed the descriptive results from the field studies.

**Table ES-1 Frequencies of Types of Interactions by Facility Types**

| Type of Facility (cases) | No Deviation or Deviated in Lane | | Encroached in Adjacent Lane or Passed | | Queued Behind Cyclist | |
|---|---|---|---|---|---|---|
| | Low | High | Low | High | Low | High |
| Adjacent Through Lane (3) | 98.0% | 99.2% | 0.8% | 1.6% | 0.0% | 0.4% |
| Buffered Bike Lane (9) | 93.1% | 100.0% | 0.0% | 6.9% | 0.0% | 0.4% |
| Striped Bike Lane (8) | 57.0% | 99.9% | 0.1% | 43.0% | 0.0% | 3.3% |
| Faded Bike Lane (1) | 87.4% | 87.4% | 3.1% | 3.1% | 9.5% | 9.5% |
| Wide Shoulder (4) | 73.1% | 97.5% | 2.5% | 25.9% | 0.0% | 2.1% |
| Narrow Shoulder (2) | 26.5% | 36.7% | 59.7% | 68.1% | 3.6% | 5.5% |
| Sharrows (4) | 3.1% | 61.5% | 8.3% | 82.8% | 2.4% | 30.2% |
| Shared Lane (signed) (5) | 4.1% | 13.2% | 15.1% | 40.5% | 54.6% | 80.8% |
| Shared Turn Lane (1) | 41.4% | 41.4% | 1.4% | 1.4% | 57.1% | 57.1% |
| Shared - Center Yellow (2) | 70.0% | 70.2% | 25.0% | 29.8% | 0.0% | 5.0% |
| No Facility (6) | 46.0% | 70.0% | 20.3% | 46.9% | 3.1% | 17.8% |

These results have several implications for design. Given an objective of increasing the predictability of driver behavior, buffered or striped bicycle lanes offer advantages over other types of facilities where space and resources allow. Whether sharrows are associated with more consistent driver behaviors during interactions with cyclists may depend on site-specific circumstances. Although sharrows may alert drivers to the potential presence of cyclists, traffic impacts on roadways with sharrows may not differ significantly from roadways with no facilities. Signs indicating bicyclists may occupy lanes also may alert drivers to the potential presence of cyclists, but there is no evidence from the cases in this study that interactions on roadways marked only with signs differ from roadways with no facilities. Thus, from the perspective of reducing potential traffic impacts such as queuing behind cyclists, bicycle lanes are to be preferred over sharrows or signage.

# CHAPTER 1: INTRODUCTION

Federal, state, and local transportation policies encourage multimodal planning and the design of roadways and streets to accommodate bicyclists and pedestrians as well as motor vehicles. To assist planners and engineers responsible for implementing these policies, several organizations and agencies, including the American Association of State Highway Transportation Officials (AASHTO), the National Association of City Transportation Officials (NACTO), Federal Highway Administration (FHWA), and the Minnesota Department of Transportation (MnDOT), have published manuals that provide guidelines for the design of bicycle facilities (AASHTO 2012, NACTO 2011 and 2014, FHWA 2009, MnDOT 2007). These manuals summarize the advantages and disadvantages of different types of facilities and factors that influence or constrain their application and use. Although many of these guidelines are based on the results of field evaluations of different facilities, not all designs have been evaluated, and additional information about the effects of different designs and design elements will help inform engineering judgement.

MnDOT and the Local Road Research Board funded this research study, “Traffic Impacts of Bicycle Facilities,” to increase understanding of the effects of bicycle facilities on driver behavior and traffic flows. The objectives of this study were to review existing design guidelines and the literature on the effects of bicycle facilities, identify needs for evaluation of facilities, select facilities to be evaluated, complete field evaluations, and summarize the implications for design. All major tasks in the project, including the literature review, the determination of field methods, the selection of sites, and the interpretation of study results were done in collaboration with a Technical Advisory Panel (TAP) established by MnDOT. This report summarizes the project’s findings:

- Chapter 2 is a review of the literature on the design of bicycle facilities and their impacts on traffic, including driver behavior.
- Chapter 3 summarizes field methods and procedures used to evaluate bicycle facilities, including criteria used to select sites for evaluation.
- Chapter 4 summarizes the results of field evaluations, focusing on driver behaviors when overtaking bicyclists on different types of facilities.
- Chapter 5 discusses the implications of the study for design, highlights areas where findings augment current guidance, and includes recommendations for further study.

# CHAPTER 2: THE DESIGN AND EVALUATION OF BICYCLE FACILITIES: A REVIEW OF THE LITERATURE

The research team initiated the project with a review of the literature on the design and effects of bicycle facilities. This literature has grown rapidly over the past 20 years as federal, state, and local governments have collaborated and experimented to develop facilities that can achieve the objectives of policies that call for safe, efficient multimodal transportation systems. The review focused on the effects of facilities and individual design components on the safety of cyclists and on traffic impacts, including driver behavior and conflicts. Special emphasis was placed on major national guidance documents (AASHTO 2012, NACTO 2011, 2014) other state guidance documents such as the MnDOT Bikeway Facilities Design Manual (2007), and research evaluations of facilities published in peer-reviewed journals or by federal, state, and local agencies. Information from these documents is summarized in a set of matrices that are useful for identifying which documents provide guidance or evaluations of specific types of facilities. The review also summarizes relevant, illustrative information from Complete Streets studies in Minnesota because the information may provide useful context for interpretation of results. The review concludes with a discussion of gaps in knowledge about the effects of bicycle facilities and the need for additional evaluation.

## 2.1 APPROACH AND METHODS

The approach to the literature review, including the strategy for search and retrieval, is summarized in Figure 2.1. The approach included four steps:

1. Google and other database searches using a broad set of keywords;
2. Retrieval, assessment, and screening of publications for relevance to the project;
3. Review of publication references and additional document retrieval;
4. Screening and information extraction, including design elements and findings.

Search keywords used in Step 1 included: "biking", "cycling", "facilities", "amenities", "policy", "guideline", "manual", "bicycle lane", "midblock conflict", "intersection conflict", "rail crossing conflict", and "design solution." The search identified 44 bicycle facility design manuals and 31 published research papers that reported results of implementation and/or assessments of different facility designs. The procedures focused on design and evaluation of bicycle facilities so general manuals such as the Manual of Uniform Traffic Control Devices were not included.

In Step 2, these documents and studies were screened pursuant to sets of criteria. Guidance documents were examined for redundancy. Upon review of several state and local guidance documents, it became clear they drew heavily on similar sources (e.g., documents published by AASHTO or NACTO) and included little new information. Guidance documents that seemed to replicate other sources therefore were excluded from further review. Different criteria were used to determine whether a research evaluation of a design or facility should be included. For a research study to be included, the evaluation had to address conflicts such as intersection, trail-crossing, or midblock conflicts. Second, the study had to include bike facilities, particularly on-street facilities such as wide curb lanes, colored bike lanes, bike lane markings, or state-of-the-art facilities such as bike boxes or pocket lanes. Studies that investigated

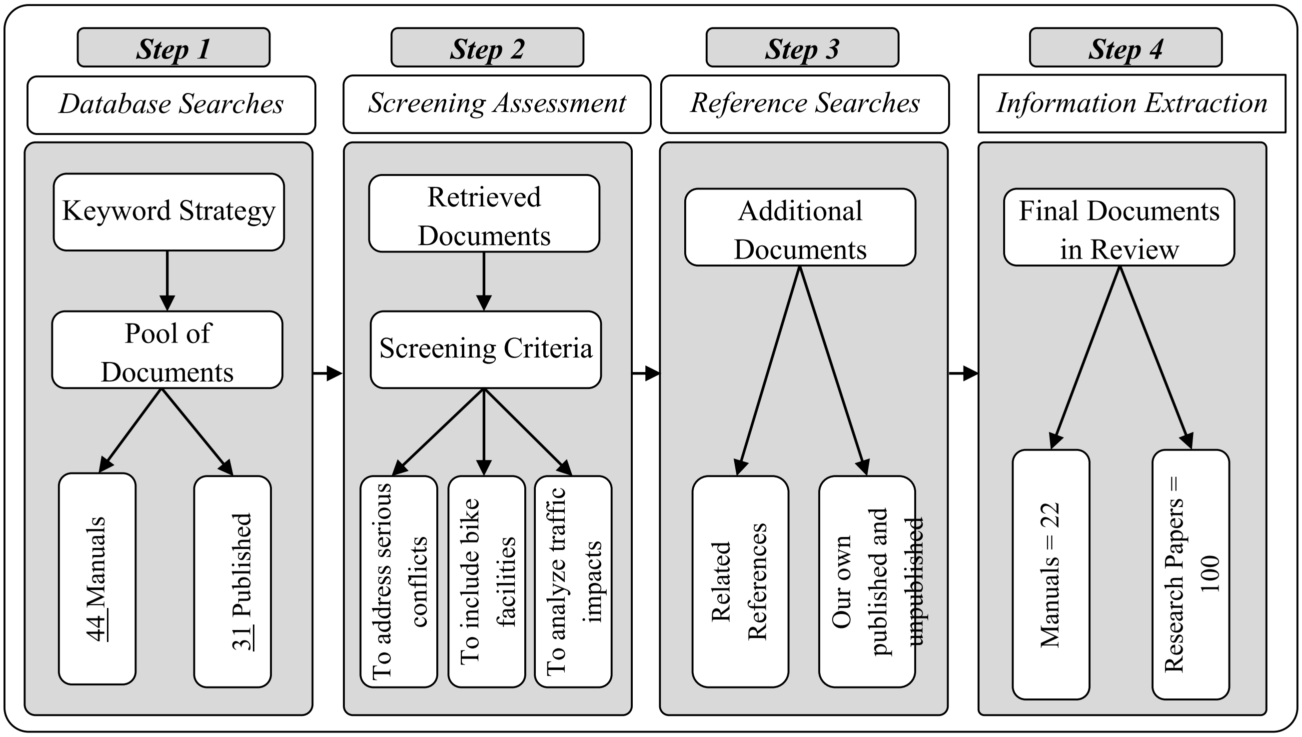


Figure 2.1 Approach to Literature Review

and measured the influence of on-street facilities on traffic and the behavior of drivers of motorized vehicles were targeted. The search was limited to English language studies. There were no criteria related to the research design and publication date, but information about the research approach and methods was collected.

Step 3 was an effort to expand the review by including relevant documents that were referenced and mentioned in the articles retained following the Step 2 assessment. Some additional guidance documents were identified but were not included in the summary presented here because they provided little or no new information about designs. Although these additional documents are not summarized in this review, they are included in the list of references. Along with additional searches, Step 3 increased the number of documents in the review to 122. Step 4 involved selection of documents for information extraction. Based on relevance to the project scope and the other criteria outlined previously, literature review includes 22 design manuals or guidance documents and 100 research evaluations of the effects of bicycle facilities.

## 2.2 ANALYSES AND RESULTS

Results from our review of these documents are summarized in tables 2-1 through 2-4. Table 2-1 lists and includes descriptions of the individual design guidelines extracted from the 22 manuals. Table 2-2 groups these guidelines in eight categories and identifies the manuals that include guidance on each of the designs. Table 2-3 lists the studies that evaluated the influence of at least one type of bike facility or design. Table 2-4 summarizes findings from research evaluations of these studies, specifically their impacts on (1) bicycling volumes or mode share; (2) the safety of cyclists, and (3) traffic impacts, including conflicts between bicyclists and other road users.

### 2.2.1 Categorization of Bicycle Facility Design Guidelines

Bike facilities may be divided into two major categories: off-street and on-street facilities. Off-street facilities, as the name implies, include facilities such as multi-use paths and bicycle parking racks that are physically separated from motorized vehicles. On-street facilities, on the other hand, encompass a range of design treatments including striped shoulders, drain grates, pavement markings, signage, and sharrows on roadways. Because the potential for conflict between motorized vehicles and cyclists occurs mostly on shared roadways, the primary focus of this literature review is on-street facilities.

As noted, Table 2-1 lists and defines 63 individual design guidelines that were extracted from the guidance documents identified in the literature review. Most of guidance documents grouped or categorized the guidelines in different ways, and no single document included all the guidelines. For example, one guidance document classified the guidelines into the five major categories:

- alignments,
- cross-sections,
- intersections,
- design details, and
- traffic control guidelines.

Within these categories, the manuals placed the most of the guidelines (e.g., pavement surfaces, bollards, detours, delineators, drainage grates, and lighting) in the design details component. NACTO (2007), in comparison, placed all guidelines in five different categories:

- bike lanes,
- cycle tracks,
- intersections,
- bicycle signals, and
- bikeway signing and marking.

NACTO includes bike boxes, refuge islands, and intersection crossings in the intersection category. The NACTO bike lanes category encompasses conventional bike lanes, buffered bike lanes, contra-flow bike lanes, and left-side bike lanes.

The AASHTO (2012) guide for the planning, design, and operation of bicycle facilities incorporates a different classification scheme. This guide includes bicycle lanes on two-way streets, bicycle lanes on-one way streets, and bicycle lane widths in the bicycle lanes category. Another category, roadway design considerations, includes railroad crossings, traffic signals, bridges and viaducts, drainage grates and utility covers, and bicycles at roundabouts.

**Table 2-1 Categories and Types of On-Street Bike Facilities (2 pages)**

| Category/Type of On-Street Bicycle Facilities | | Description |
|---|---|---|
| | **1. Traffic Calming** | |
| *a.* | *Chicanes* | An artificial feature creating extra turns in a road to slow traffic for safety. |
| *b.* | *Speed humps* | Traffic calming devices that use vertical deflection to slow motor-vehicle traffic. |
| *c.* | *Lane Reconfiguration or Road Diet* | A technique to reduce the number of travel lanes or effective width of the road. |
| *d.* | *Pinch points* | A curb extension, a traffic calming measure consisting of an angled narrowing of the roadway |
| *e.* | *Choker entrances* | Intersection curb extensions or raised islands allowing full bicycle passage while restricting vehicle access to and from a Bicycle Boulevard. |
| *f.* | *Woonerf* | Techniques include shared space, traffic calming, and low speed limits. |
| | ***2. Signalization and Marking*** | |
| *a.* | *Signing* | A cost-effective yet highly-visible treatment that can improve the riding environment for cyclists. |
| *b.* | *Bike lane symbol* | Any kind of device or material that is used on a road surface in order to convey official information. |
| *c.* | *Wide yellow center line stripe* | The most common forms of road surface markings, providing separation between traffic moving in opposite directions. |
| *d.* | *Lines spaced* | |
| *e.* | *Traffic signals* | Signaling devices positioned at road intersections to control competing flows of traffic. |
| *f.* | *Length of the broken line* | |
| | ***3. Geometric Design*** | |
| *a.* | *Bicycle design speed* | |
| *b.* | *Transition distance* | |
| *c.* | *Sight distance* | |
| | ***4. Intersection Components*** | |
| *a.* | *Bike box* | A right angle extension to a bicycle lane at the head of a signalized intersection. |
| *b.* | *Modern roundabouts* | A type of circular intersection or junction in which road traffic flows almost continuously in one direction around a central island. |
| *c.* | *Lanes at Intersections* | Refers to how lanes configured for through traffic |
| *d.* | *Lanes and Turning Movements* | Refers to how lanes configured for turning movements |
| *e.* | *Refuge area* | A small section of pavement or sidewalk, completely surrounded by asphalt or other road materials, where cyclists can stop before finishing crossing a road. |
| *f.* | *Midblock crossings* | At uncontrolled intersections a bicycle crossing island can be provided to allow cyclists to cross one direction of traffic at a time when gaps in traffic allow. |
| *g.* | *Pocket lane* | A section of bike lane that has a lane for vehicles on either side as the result of inserting a right-turn lane to the right of the bike lane. |
| | ***5. Cross section Components*** | |
| *a.* | *Bridges* | A structure built to span physical obstacles such as a body of water, valley, or road, for the purpose of providing passage over the obstacle. |
| *b.* | *Railroad crossings* | At grade crossing with rail track.. |
| *c.* | *Bicycle Crossing of Interchange Ramp* | At grade crossing with ramp for vehicles entering or exiting limited access roads. |
| *d.* | *Crossing surface* | The particular type of surface at the crossing. |
| *e.* | *Crossing angle* | As measured from crossing entry point to crossing exit point |

| | | |
|---|---|---|
| *f.* | *Adjacent path crossings* | At grade crossing with a path adjacent to the principal roadway. |
| *g.* | *Toucan crossing* | A type of pedestrian crossing found in the United Kingdom that also allows bicycles to be ridden across. |
| *h.* | *Diagonal diverter* | Place a barrier diagonally across an intersection, disconnecting the legs of the intersection. |

**Table 2-1 Categories and Types of On-Street Bike Facilities (Continue)**

| Category/Type of On-Street Bicycle Facilities | | Description |
|---|---|---|
| | | **6. Bikeway Component** |
| *a.* | *Bike lane widths* | A separated lane from vehicle travel lanes with striping and also include pavement stencils. |
| *b.* | *Paved width 2-directional shared use path* | Low-volume streets where motorists and bicyclists share the same space. |
| *c.* | *Paved width 1-directional shared use path* | Low-volume streets where motorists and bicyclists share the same space. |
| *d.* | *Wide curb lanes* | A traffic lane next to the curb which is extra wide so a motorist can safely pass a bicyclist without having to change lanes. |
| *e.* | *Colored bike lanes* | A colored path to guide bicyclists through major vehicle and bicycle conflict points. |
| *f.* | *Combined bicycle and parking width* | As measured to travel lane |
| *g.* | *Buffered bike lanes* | A conventional bicycle lane paired with a designated buffer space separating the bicycle lane from the adjacent motor vehicle travel lane and/or parking lane. |
| *h.* | *Floating bike lanes* | A design solution to provide a bike lane on a street where parallel parking is permitted during certain times of the day but not during other times. |
| *i.* | *Advisory bike lanes* | A similar lane to a regular bike lane, but is used on low-volume streets that are narrow. |
| *j.* | *Bike passing lane* | |
| *k.* | *Contra flow Bike Lane* | A lane in which traffic flows in the opposite direction of the surrounding lanes. |
| *l.* | *Cycle tracks* | A hybrid type bicycle facility that combines the experience of a separated path with the on-street infrastructure of a conventional bicycle lane. |
| *m.* | *Raised bicycle lanes* | A protected bikeway without bollards or barriers, instead building the bikeway at an intermediate level between the sidewalk and roadway. |
| *n.* | *Bicycle boulevards* | A lower-volume, lower-speed street that has been optimized for bicycle traffic. |
| *o.* | *Bike Lanes and Diagonal Parking* | Measures to address conflicts |
| *p.* | *Bike Lanes and Bus Lanes* | Measures to address conflicts |
| *q.* | *Uphill climbing bicycle lanes* | A hybrid bicycle facility that includes a five-foot bicycle lane on one side of the roadway (in the uphill direction) and a shared lane pavement marking on the other side of the roadway. |
| *r.* | *Tracking widths and grades* | |
| *s.* | *Sharrows* | Painted lane markings (i.e., bicycles and arrows) indicating lane is shared |
| | | **7. Road Design Components** |
| *a.* | *Paved shoulders* | Paved roadways with striped shoulders wide enough for bicycle travel. |
| *b.* | *Bikeway detours* | Adequate information to bypass the closed section of roads. |
| *c.* | *Bollard placement* | A short vertical post to Segregate cycle facilities from the main route. |
| *d.* | *Surface types* | Asphalt, concrete, etc. |
| *e.* | *Drainage and Drainage Grates* | A depression running parallel to a road designed to collect rainwater flowing along the street and divert it into a storm drain. |

| | | |
|---|---|---|
| *f.* | *Grade separated overcrossing* | |
| *g.* | *Lighting* | A raised source of light on the edge of a road or walkway, which is used to provide light when it is needed. |
| *h.* | *Flange opening* | |
| | **8. Separators** | |
| *a.* | *Guard rails* | A system designed to keep people or vehicles from straying into dangerous or off-limits areas. |
| *b.* | *Rumble strips* | A road safety feature to alert inattentive drivers of potential danger, by causing a tactile vibration and audible rumbling transmitted through the wheels into the vehicle interior. |
| *c.* | *Separation* | |
| *d.* | *Fencing* | |
| *e.* | *Barrier post striping* | |

The MnDOT (2007) bikeway facility design manual, in comparison, includes bikeways and left-turn movements, bikeways at roundabouts, bikeways at interchanges, painted refuge islands for bicyclists, advanced stop lines, and railroad crossing intersections in the intersection category. The geometric design component of the MnDOT manual includes sight-distance, transition distance, and design speed. The city Portland, Oregon organizes its guidelines differently.

These few examples make it clear there is no single, correct way to categorize designs and facilities. Based on information and the different approaches to categorization used in the different design manuals, we organize the design guidelines in eight categories:

1. Traffic Calming Components
2. Signalization and Marking
3. Geometric Design Components
4. Bikeway Components
5. Intersection Components
6. Cross section Components
7. Road Design Components
8. Separator Components

The purpose of this categorization scheme is to group designs by purpose or function. Although this scheme may be somewhat arbitrary, it is useful for purposes of organization and to facilitate comparison.

Table 2-2 is a matrix that categorizes the design guidelines within these eight categories and lists which of the guidance documents include information about the guideline. Some types of design guidelines are more likely to be included in manuals than others. Across these categories, the number of individual designs (or design guidelines) ranges from 3 to 19, with the most design options included for bikeway components. That is, most of the manuals seem to focus on the design of bikeways, with less attention given to other components of design.

The guidance documents are listed in chronological order, from oldest to most recent to illustrate that the number of design options has increased over time as bicycling has become more popular and policies to encourage and support bicycling have been adopted. Some of the documents (e.g., two funded by the Local Road Research Board (LRRB)) are narrower in scope and consequently address fewer design guidelines, even though they have been published more recently. For example, one LRRB (2013) focuses on trail crossings and thus fewer design guidelines are relevant.

**Table 2-2 Summary of Guidelines in Bicycle Facilities Design Manuals**

| Manuals | Year | 1. Traffic Calming | | | | | | 2. Signalization and Marking | | | | | | 3. Geometric Design | | | 4. Intersection Components | | | | | | | 5. Cross section Components | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *a. Chicanes* | *b. Speed humps* | *c. Lane reconfiguration or road diet* | *d. Pinch points* | *e. Choker entrances* | *f. Woonerf* | *a. Signing* | *b. Bike lane symbol* | *c. Wide yellow center line stripe* | *d. Lines spaced* | *e. Traffic signals* | *f. Length of the broken line* | *a. Bicycle design speed* | *b. Transition distance* | *c. Sight distance* | *a. Bike box* | *b. Modern roundabouts* | *c. Lanes at intersections* | *d. Lanes and turning movements* | *e. Refuge area* | *f. Midblock crossings* | *g. Pocket lane* | *a. Bridges* | *b. Railroad crossings* | *c. Bicycle crossing of interchange ramp* | *d. Crossing surface* | *e. Crossing angle* | *f. Adjacent path crossings* | *g. Toucan crossing* | *h. Diagonal diverter* |
| London | 1998 | × | × | | × | | | × | × | | | × | × | × | × | × | | × | × | × | × | | | × | | | | | × | × | |
| AASHTO | 1999 | | | | | | | × | × | × | × | × | × | × | × | × | | × | × | × | × | × | | × | × | × | | | × | | |
| Vermont | 2002 | | | | | | | × | × | | × | × | | × | | | | | × | × | × | | | × | × | × | | | | | |
| Irish | 2002 | × | | | × | | × | | × | | | | | × | | × | × | × | × | × | × | | | × | | × | | | × | × | |
| Chicago | 2002 | | | | | | | × | × | × | | | | | | | | | × | | | × | | | | | | | | | |
| South Carolina | 2003 | | | | | | | | | | | | | | | | | | | | × | | | × | | | | | | | |
| South Africa | 2003 | | | | | | | × | | | | × | | × | | × | | | | | × | × | | | | | | | × | | |
| New South Wales | 2005 | | × | | | | | × | × | | | × | | × | × | × | | × | × | × | × | × | | × | | × | | | | | |
| Highway Design | 2006 | | | | | | | × | | | | | | | | | | | | × | | | | | | | | | | | |
| Minnesota | 2007 | | | | | | | × | × | × | | × | | × | × | × | | × | × | × | × | | | × | × | × | | × | | | × |
| Tacoma | 2009 | × | × | | | × | | × | × | | | | | | | | × | × | × | | × | | × | | | | | | | | |
| Los Angles | 2010 | × | | × | | × | | × | × | | | × | | × | | | × | × | × | × | × | × | × | × | × | × | | | | | × |
| Minneapolis | 2010 | × | × | | | | | × | × | | | | | | | | | × | × | | | | | × | × | | | | | | × |
| San Antonio | 2011 | | | | | | | × | × | | | | | | | | | | | | | × | × | × | × | | | | | | |
| Oregon | 2011 | | × | | | × | × | × | × | | | × | | | × | × | × | × | × | × | × | × | | | × | | × | × | | | |
| National Cycle | 2011 | | | | | | | × | × | | | × | | × | × | × | | × | | × | | | × | × | | × | | | | | |
| NACTO | 2011 | | × | | | | | × | × | | | | | | | | × | | × | × | × | × | × | | | × | | | | | |
| AASHTO | 2012 | × | × | × | | × | | × | × | × | × | × | | × | × | × | | × | × | × | × | × | | × | × | × | × | × | × | | |
| Redmond | 2012 | | | | | | | | × | | | | | | | | | | × | × | | | | × | × | | | | | | |
| Maryland | 2013 | | | | | | | × | × | | | | | × | × | × | | × | × | × | × | × | × | × | × | × | | | × | | |
| LRRB(Rail) | 2013 | | × | | | | | × | × | | | × | | | | × | | | | | × | × | | | × | × | | | × | | |
| LRRB(Safety) | 2013 | | | × | | | | | | | | | | | | | × | × | | × | | | | | | | | | | | |

| TOTAL | - | 6 | 8 | 3 | 2 | 4 | 2 | 18 | 18 | 4 | 3 | 11 | 2 | 11 | 8 | 11 | 6 | 13 | 15 | 15 | 15 | 11 | 6 | 14 | 11 | 11 | 2 | 3 | 7 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

**Note:** Shading indicates research evaluation of design or facility is summarized in Table 2-4.

### Table 2-2 Summary of Guidelines in Bicycle Facilities Design Manuals (Continued)

| Manuals | Year | 6. Bikeway Component | | | | | | | | | | | | | | | | | | | 7. Road Design Components | | | | | | | | 8. Separators | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *a. Bike lane widths* | *b. Paved width 2-directional shared use path* | *c. Paved width 1-directional shared use path* | *d. Wide curb lanes* | *e. Colored bike lanes* | *f. Combined bicycle and parking width* | *g. Buffered bike lanes* | *h. Floating bike lanes* | *i. Advisory bike lanes* | *j. Bike passing lane* | *k. Contra flow bike lane* | *l. Cycle tracks* | *m. Raised bicycle lanes* | *n. Bicycle boulevards* | *o. Bike lanes and diagonal parking* | *p. Bike lanes and bus lanes* | *q. Uphill climbing bicycle lanes* | *r. Tracking widths and grades* | *s. Sharrows: Shared lane markings* | *a. Paved shoulders* | *b. Bikeway detours* | *c. Bollard placement* | *d. Surface types* | *e. Drainage and drainage grates* | *f. Grade separated overcrossing* | *g. Lighting* | *h. Flange opening* | *a. Guard rails* | *b. Rumble strips* | *c. Separation* | *d. Fencing* | *e. Barrier post striping* |
| London | 1998 | × | | | × | × | × | | | × | | × | | × | | | × | | × | | | | × | × | × | × | × | | × | × | × | | |
| AASHTO | 1999 | × | × | × | × | | × | | | | | | | | | | | | | | × | | × | | × | | × | | | | | | × |
| Vermont | 2002 | × | | | × | | | | | | | | | | | | | | × | | × | | | | × | | | | × | × | | | × |
| Irish | 2002 | | | | × | × | × | | | × | | × | × | × | | × | × | | | | × | | × | × | | × | × | | | × | × | | |
| Chicago | 2002 | × | | | × | | × | | | | | | | | | | | | | | | | | | | | | | | | | | |
| South Carolina | 2003 | × | | | | | | | | | | | | | | | | | | | × | | | | × | | | | | × | | | |
| South Africa | 2003 | × | × | × | | | | | | | | | | | | | | | | | × | | | | | | × | | × | | | | |
| New South Wales | 2005 | × | × | × | | × | × | | | | | × | | | | | × | | | | × | | × | × | × | | | | × | | × | | |
| Highway Design | 2006 | × | × | × | × | | | | | | | | | | | | | | | | × | | | | × | | × | | | | | | |
| Minnesota | 2007 | × | × | × | × | | × | | | | × | × | | | | × | × | | × | | × | | × | × | × | × | × | | × | × | × | × | × |
| Tacoma | 2009 | × | | | | × | × | × | × | × | × | × | × | | × | | | | | × | × | | | | | | | | | | × | | |
| Los Angles | 2010 | × | × | × | × | × | × | | × | | | × | × | × | | × | × | × | | × | × | | × | × | × | × | × | | | × | × | × | × |
| Minneapolis | 2010 | × | × | × | × | | × | | | | | | | | × | | | | | | × | × | | | × | | | | | × | | | |
| San Antonio | 2011 | × | × | × | | | × | × | | | | | | | × | | | | | × | × | | | | | | | | | | | | |
| Oregon | 2011 | × | × | × | × | × | × | × | × | × | × | | × | | × | × | × | | | × | × | | × | × | × | | × | × | | × | × | | × |
| National Cycle | 2011 | | | | × | × | | | | × | | × | | | | | × | | × | | | | × | × | × | | × | | × | × | × | | |
| NACTO | 2011 | × | × | × | × | × | | × | × | | | × | | | | | | | | × | | | | × | | | × | | | | × | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AASHTO | 2012 | × | × | × | × | | × | | | | | × | | | × | × | | | | × | × | | × | × | × | × | × | × | × | × | × | | × |
| Redmond | 2012 | × | | | | | × | | | | | | | | × | | | | | × | × | | × | | × | | | | × | | | | |
| Maryland | 2013 | × | | | × | | | | | | | | | | | × | | | × | × | × | | × | × | × | | | | | × | × | | × |
| LRRB (Rail) | 2013 | | | | | | | | | | | | | | | | | | | | | | × | | | | × | | | | | | × |
| LRRB (Safety) | 2013 | × | | | | | × | | | | | | | | × | | | | | | × | | | | × | × | × | | | × | | | |
| TOTAL | - | 19 | 11 | 11 | 14 | 8 | 14 | 4 | 4 | 5 | 3 | 9 | 4 | 3 | 7 | 6 | 7 | 1 | 5 | 8 | 17 | 1 | 12 | 10 | 15 | 6 | 13 | 2 | 8 | 12 | 11 | 2 | 8 |

**Note:** Shading indicates research evaluation of design or facility is summarized in Table 2-4.

Table 2-2 also includes a count of the number of guidance documents in which each guideline appears. These counts, which range from 1 to 19, can be interpreted as indicators of the potential for application in particular settings or as a measure of how frequently the measures might be considered by engineers responsible for planning bicycle treatments. For example, 19 of the 22 documents provide guidance for the width of bike lanes, and 18 provide guidance on signage and bike lane symbols. In contrast, uphill climbing bicycle lanes and bollard placement each are addressed in only one guidance document (i.e., Los Angeles (2010) and Minneapolis (2010), respectively).

In Table 2-2, the names of some guidelines are shaded and others are not. Shading indicates that the design element has been evaluated in one or more of the research evaluations included in this review. For example, this review identified evaluations of bicycle lane widths (Design element 6.a.) but none floating bike lanes (Design element 6.h.) or combined bus and bicycle lanes (Design element 6.p.). Table 2-2 thus provides information about gaps in our knowledge of the effects of different types of bicycle facilities.

### 2.2.2 Evaluations of Bicycle Facility Design Guidelines

Many recent studies have addressed conflicts between bicyclists and vehicles and attempted to measure or assess the influence of on-street bicycle facilities on the behavior of cyclists and drivers. These studies date to at least the mid-1970s when Kaplan made an effort to calculate bicycle-related accident rates on major roads, minor roads, on-road bike lanes, and off-road bike lanes in the United States. In an analysis of a sample (n=854) of collisions and serious falls, he found that approximately 7 percent occurred in on on-road bike lanes. Since the 1970s, the number of studies has been growing consistently.

Table 2-3 summarizes the year, sample size, and analytic methods used in each of the research studies included in this review. The table is organized by methodology and year of publication. The number of research studies has grown in the recent past: more than 40% of the studies have been published since 2010. Given lags in incorporating research findings into technical guidance documents, this fact means that it is likely the recommendations included in many design manuals need to be updated.

A second observation is that while approaches and sample sizes have varied, researchers have drawn on a relatively consistent set of methods. These methods include videotaping of facilities, other types of observational data collection, surveys of bicyclists and drivers, and analyses of census and other secondary data. Dill et al. (2011), for example, investigated the influence of bike boxes at 10 signalized intersections in Portland, Oregon. Their sample included 918 hours of video tape, one of the largest samples reported among these studies. Videotaping of facility use, combined with manual reduction of the video, is perhaps the most frequent approach to evaluation of facilities. Comparisons are complicated, however, because the level of detail reported in studies varies. Some researchers, for example, focus on the number of cyclists observed, not the number of hours of tape analyzed to obtain the sample of cyclists for analysis. Some researchers have combined analyses of video footage method with other methods, including surveys and analyses of GPS data collected from facility users.

**Table 2-3 Summary of Previous Studies (3 pages)**

| **Author** | **Year** | **Location** | **Number of Sample** | **Method** | |
|---|---|---|---|---|---|
| | | | | *Survey* | *Analysis* |
| 1. Daff | 2005 | Australia | 10,000 car drivers | Video footage | Descriptive |
| 2. Jensen | 2007 | Denmark | 407 cyclists | Video clips | Statistical |
| 3. Hunter | 2000 | Oregon | 1414 cyclists / - | Video + survey | Before and after |
| 4. Hunter | 2000 | Oregon | 50 hours/ 200 cyclists | Video + survey | Before and after |
| 5. Wall | 2003 | Surrey | - | Video + survey | Before and after |
| 6. Sadek | 2007 | Vermont | 88 hour/ 106 cyclist | Video + survey | Before and after |
| 7. Flannery | 2010 | U.S. | 1731 hour / 89 | Video + survey | Descriptive |
| 8. Turner | 2011 | New Zealand | 383 approaches | Video + survey | Before and after |
| 9. Dill | 2011 | Oregon | 918 hours /468 cyclists | Video + survey | Before and after |
| 10. Monsere | 2011 | Oregon | 36 hours/ 744 individuals | Video + survey | Descriptive |
| 11. Blenski | 2011 | Minnesota | 27 hours/ 494 cyclists | Video + survey | Descriptive |
| 12. Goodno | 2013 | Washington | 6 h per intersection/351 cyclists | Video + survey | Descriptive |
| 13. Monsere | 2014 | U.S. | 168 hours/ 16,393 bicyclists | Video + survey | Before and after |
| 14. Harkey | 1996 | Florida | 1583 interactions | Video | Statistical |
| 15. KWON | 1997 | Japan | 30 minutes | Video | Statistical |
| 16. Gårder | 1998 | Sweden | 315 hours | Video | Before and after |
| 17. HUNTER | 1999 | U.S. | 4,600 cyclists | Video | Video analysis |
| 18. Hunter | 1999 | Florida | 757 cyclists | Video | Before and after |
| 19. Pein | 1999 | Florida | 1379 cyclists | Video | Before and after |
| 20. Hunter | 1999 | Florida | 638 cyclists | Video | Statistical |
| 21. Moeur | 2000 | Arizona | 28 cyclists | Video | Before and after |
| 22. Alta Group | 2004 | California | 140 hours | Video | Before and after |
| 23. Hunter | 2004 | Florida | 1,862 images | Video | Before and after |
| 24. Atkins | 2005 | London | 240 hours | Video | Video analysis |
| 25. Hunter | 2005 | Florida | 364 images | Video | Before and after |
| 26. Hallett, | 2006 | Texas | 7500 observations | Video | Statistical |
| 27. Hunter | 2008 | Florida | 1,181 cyclists | Video | Before and after |
| 28. Loskorn | 2010 | Texas | - | Video | Before and after |
| 29. Duthie | 2010 | Texas | 3,900 observations | Video | Statistical |
| 30. Sando | 2010 | Florida | 950 events | Video | Statistical |

| | | | | | |
|---|---|---|---|---|---|
| 31. Hunter | 2010 | Massachusetts | 50 hours | Video | Before and after |
| 32. Brady | 2011 | Texas | 3150 observations | Video | Before and after |
| 33. Ross | 2011 | Oregon | 159 crossings | Video | Before and after |
| 34. LaMondia | 2012 | Texas | - | Video | Statistical |
| 35. Hourdos | 2012 | Minnesota | 1,920 hours | Video | Statistical |
| 36. Hunter | 2012 | Florida | 1,000 bicyclists and pedestrians | Video | Descriptive |
| 37. Barnes | 2013 | Oregon | 54 hours | Video | Before and after |
| 38. Sayed | 2013 | Canada | 229 cyclists | Video | Video analysis |
| 39. Farley | 2013 | Oregon | 528 hours | Video | Video analysis |
| 40. Hourdos | 2013 | Minnesota | 359 hours | Video | Before and after |
| 41. Chen | 2013 | China | 20 hours | Video | Statistical |
| 42. Kay | 2013 | Michigan | 2425 events | Video | Before and after |
| 43. Luo | 2013 | China | 2 hours | Video | Statistical |
| 44. Allen | 2005 | London | 6041 cyclists | Video | Video analysis |
| 45. Love | 2012 | Maryland | 10.8 h + 586 vehicle passes | Video | |
| 46. Mehta | 2013 | Canada | 5,227 passing events | Ultrasonic sensor and GPS | Descriptive |

**Table 2-3 Summary of Previous Studies (Continued)**

| Author | Year | Location | Number of Sample | Method | |
|---|---|---|---|---|---|
| | | | | *Survey* | *Analysis* |
| 47. Krizek | 2006 | Minnesota | 1653 individuals | Survey + GIS | Statistical |
| 48. Kaplan | 1975 | U.S. | 3270 bicycling | Survey | Descriptive |
| 49. Bohle | 2000 | Germany | 1,500 cyclists | Survey | Descriptive |
| 50. Moudon | 2005 | Washington | 608 individuals | Survey | Statistical |
| 51. Dill | 2006 | Oregon | 566 adults | Survey | Descriptive |
| 52. Alta Group | 2008 | Oregon | 1520 individuals | Survey | Descriptive |
| 53. Geus | 2008 | Belgium | 343 adults | Survey | Statistical |
| 54. Emond | 2009 | U.S. | 965 individuals | Survey | Statistical |
| 55. Cervero | 2009 | Colombia | 1315 individuals | Survey | Statistical |
| 56. Sener | 2009 | Texas | 810 cyclists | Survey | Statistical |
| 57. Larsen | 2010 | Canada | 2917 cyclists | Survey | Statistical |
| 58. Teschke | 2012 | Canada | 690 individuals | Survey | Descriptive |
| 59. Hamann | 2013 | Iowa | 147 bicycle crashes | Survey | Statistical |
| 60. Harris | 2013 | Canada | 1761 injuries | Survey | Statistical |
| 61. Kim | 2014 | California | 418 individuals | Survey | Statistical |
| 62. Krizek | 2004 | Minnesota | 453 individuals | Sp survey | Statistical |
| 63. Sener | 2009 | Texas | 1621 individuals | Sp survey | Statistical |
| 64. Chaurand | 2013 | France | 336 cyclists + 92 drivers | Sp survey | Statistical |
| 65. McHenry | 1985 | Maryland | 32 cyclists | Photographic record | Descriptive |
| 66. Newman | 2002 | New Zealand | - | Observational + survey | Descriptive |

| | | | | | |
|---|---|---|---|---|---|
| 67. Jilla | 1974 | Indiana | Less than 68 observation | Observational | Descriptive |
| 68. Wachtel | 1994 | California | 2976 observations | Observational | Before and after |
| 69. Jonsson | 2007 | Sweden | 2823 interactions | Observational | Before and after |
| 70. Jenson | 2007 | Denmark | 5898 crashes | Observational | Before and after |
| 71. Garrard | 2008 | Australia | 6589 cyclists | Observational | Statistical |
| 72. Furth | 2010 | Massachusetts | 400 observations | Observational | Statistical |
| 73. Shurbutt | 2010 | U.S. | 22 sites | Observational | Before and after |
| 74. Torbic | 2014 | Massachusetts and Illinois | 4,965 cyclists | Observational | Descriptive |
| 75. Twisk | 2012 | Europe | 470 years of driving | Naturalistic | Descriptive |
| 76. Dill | 2008 | Oregon | 164 adults | GPS | Descriptive |
| 77. Dill | 2009 | Oregon | 166 cyclists | GPS | Descriptive |
| 78. Minikel | 2012 | California | 121 counts | Cyclist count | Statistical |
| 79. Hels | 2007 | Denmark | 171 crashes | Crash data + observational | Statistical |
| 80. Daniels | 2008 | Belgium | 812 crashes | Crash data + observational | Before and after |
| 81. Dougald | 2012 | Virginia | 13 crashes/ 425 individuals | Crash data + nu-metrics counters + survey | Before and after |
| 82. Lusk | 2011 | Canada | 531 injuries/5621 counts | Crash data + counts recording | Descriptive |
| 83. Lusk | 2013 | U.S. | 24 cycle track | Crash data + counts recording | Descriptive |
| 84. KLOP | 1999 | North Carolina | 1,025 crashes | Crash data | Statistical |

**Table 2-3 Summary of Previous Studies (Continued)**

| Author | Year | Location | Number of Sample | Method | |
|---|---|---|---|---|---|
| | | | | *Survey* | *Analysis* |
| 85. Persaud | 2001 | U.S. | 23 intersections | Crash data | Before and after |
| 86. Retting | 2002 | U.S. | 4606 crashes | Crash data | Statistical |
| 87. Wang | 2004 | Japan | 2,928 crashes | Crash data | Statistical |
| 88. Kim | 2007 | North Carolina | 2934 crashes | Crash data | Statistical |
| 89. Wanvik | 2009 | Dutch | 763,000 injury accidents | Crash data | Statistical |
| 90. Grundy | 2009 | London | 48,910 crashes | Crash data | Statistical |
| 91. Furth | 2011 | Utah | 1508 cyclists | Counts recording | Before and after |

| | | | | | |
|---|---|---|---|---|---|
| 92. Dill | 2003 | U.S. | 700,000 housing | Census data | Statistical |
| 93. Parkin | 2007 | UK | 8,800 wards | Census data | Statistical |
| 94. Douma | 2008 | U.S. | - | Census data | Descriptive |
| 95. Pucher | 2008 | Europe | - | Census data | Descriptive |
| 96. Krizek | 2009 | Minnesota | 51,873 Trips | Census data | Descriptive |
| 97. Daniels | 2009 | Belgium | 411 crashes | Census data | Before and after |
| 98. Pucher | 2011 | Canada and U.S. | - | Census data | Descriptive |
| 99. Chen | 2013 | New York | - | Census data | Statistical |
| 100. Leclerc | 2002 | Oregon | 427 Trips | Census | Statistical |

Another common approach involves analyses of crash data to determine risk associated with different types of facilities. Although some studies report only descriptive statistics or perhaps the results of hypothesis tests, others present insights from more advanced statistical modeling.

Some researchers have reported significant results and definitive findings, but other studies have been inconclusive. Among researchers who have focused on conflicts between types of users, several have noted that the infrequent nature of events is an obstacle to obtaining significant results. That is, given the small number of conflicts that occur, very large (and expensive) samples are needed to identify and evaluate conflicts. For example, Farley (2013) explored the safety effects of the bike boxes at eleven intersections in Portland, Oregon. Although this study included analyses of 528 hours of video, he reported that the sample of observed conflicts was too small to draw statistically significant conclusions.

The research aims of these studies also can be grouped into a small set of categories:

1. Promoting bicycling volumes and mode share;
2. Improving the level of cyclists' safety; and
3. Diminishing conflicts between bicyclists, vehicles, pedestrians, and other modes of transportation.

There is some overlap among these categories (e.g., diminishing conflicts can improve safety), but the scheme is useful for organizing the studies and comparing their findings.

Table 2-4 is a synthesis of the research literature based on these three categories. That is, Table 2-4 summarizes the research evaluations by primary aims, including whether the findings were positive, negative, or indeterminate with respect to their aims (e.g., on volumes of cycling, safety for cyclists, or effects on other modes of traffic, including conflicts). Overall, these research studies have addressed at least 29 of the guidelines in the manuals. Across the eight categories of design guidelines, most of these evaluations have focused on bikeway components. Specifically, researchers have evaluated three of seven intersection components, 12 of the bikeway components, and only two/three designs across the other six categories. Some facilities (e.g., bike lanes and bike lane symbols) have been investigated in several studies, while others (e.g., raised bicycle lanes, railroad crossings, crossing angle, choker entrances, lanes and turning movements, and bridge facilities) may have been assessed only in a single study.

In terms of safety for cyclists, researchers consistently have reported positive correlations with colored bike lanes, signage, buffered bike lanes, wider bike lane widths, rumble strips, speed humps, lighting, bicycle boulevards, and raised bicycle lanes. Conversely, depending on configurations, reporters have found negative correlations between safety and wide curb lanes, bicycle crossing on interchange ramps, railroad crossings, crossing angle, adjacent path crossings, and lanes and turning movements. For some types of designs, contradictory findings have been reported. For instance, Jonsson et al. (2007) performed a before-and-after study in Sweden to assess how bicyclists and drivers of motor vehicles interact at intersections. The results showed that motorized-vehicle drivers are more likely to give way to cyclists on a roundabout than on a link. However, in before-and-after study of accidents involving bicyclists on 91 roundabouts in Belgium, Daniels et al. (2008), concluded that the construction of roundabouts increased the number of bicyclists' injuries by 48 percent. These differences can be attributed in part to different baselines for comparison. In the Jonsson et al. (2007) study, building a roundabout increases the level of safety in comparison with the safety of link intersections. Daniels et al. (2008) explored a different question and concluded roundabouts that replaced traffic signals were associated with more accidents compared to roundabouts at other types of intersections.

In terms of conflicts, studies commonly report reductions in conflicts following installations of bike lane, bicycle boxes, paved shoulders, bike lane symbols, and rumble strips. That is, researchers reported negative correlations between conflicts (e.g., encroachments) and these types of treatments. On the other hand, positive correlations with conflict were observed with other treatments (e.g., bicycle crossings of interchange ramps, buffered bike lanes, and some cycletrack designs). For example, Monsere et al. (2011) investigated conflicts associated with two types of facilities, a cycle track and buffered bike lanes in downtown Portland. Their analysis showed that although the cycle track improved both the safety of cyclists and share of biking, it simultaneously increased conflicts between cyclists and pedestrians, particularly at intersections. Contradictory results have been reported for other types of facilities. For example, three studies reported that installation of wide curb lanes caused route conflicts, while a fourth study reported a negative correlation (i.e., a reduction in conflicts).

**Table 2-4 Research Evaluations of Bicycle Facilities: A Summary of Findings**

| Design Guideline / Facility Type | Bicycle Traffic Volume / Mode Share | | | Safety of Cyclists | | | Traffic Impacts, including Conflicts Among Users | | |
|---|---|---|---|---|---|---|---|---|---|
| | + | - | *Null* | + | - | *Null* | + | - | *Null* |
| 1.b. Speed humps | | | | 84, 99 | | | | | |
| 1.c. Lane reconfiguration or road diet | | | | 59, 99 | | | | | |
| 1.e. Choker entrances | | | | 87 | | | | | |
| 2.a. Signing | | | | 4, 31, 32, 34, 69, 99 | | | | 42 | |
| 2.b. Bike lane symbol | 56, 70 | | 94 | 22, 24, 40, 69, 74, | | 79 | | 1, 22, 31, 40, 66, 67, 69, | |
| 2.e. Traffic signals | | | | 33, 36, 73, 81, 86, 87, 99 | | | | 36 | 40 |
| 4.a. Bicycle Boxes | 28 | 3 | | 8, 9, 24, 28, 66, | | 24, 39, 44 | | 3, 9, 28 | 39, 44 |
| 4.b. Roundabouts | | | | 7, 69, 85 | 60, 80, 97 | 79 | 35 | 69 | |
| 4.d. Lanes and turning movements | | | | | 87 | | | 41 | |
| 5.a. Bridges | 96 | | | | | | | | |
| 5.b. Railroad crossings | | | | | 52, 58 | | | | |
| 5.c. Bicycle crossing of interchange ramp | | | | | 38 | | 38 | | |
| 5.e. Crossing angle | | | | | 52 | | | | |
| 5.f. Adjacent path crossings | | | | | 69 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6. Bikeway Component | 40, 45, 47, 50, 51, 52, 57, 71, 76, 77, 92, 96, 100 | | 94, 40 | 14, 17, 29, 45, 46, 59, 70, 74, 99, 100 | | 8, 65, 79 | | 14, 20, 26, 40, 45, 46, 67, 74 | |
| 6.a. Bike lane widths | | | | 8, 29, 30, 65 | | | 26, 29 | 14, 45 | |
| 6.b,c. Shared use path | 19, 37, 71 | 56 | | 32, 34, 37, 59 | | | | 19, 37 | 45 |

**Note:** Numbers in cells of tables refer to publication number in list of research evaluations, Table 2-3.

Table 2-4 Research Evaluations of Bicycle Facilities: A Summary of Findings (Continue)

| Design Guideline / Facility Type | Bicycle Traffic Volume / Mode Share | | | Safety of Cyclists | | | Traffic Impacts, including Conflicts Among Users | | |
|---|---|---|---|---|---|---|---|---|---|
| | + | - | *Null* | + | - | *Null* | + | - | *Null* |
| 6.d. Wide Curb Lanes | | | | 30 | 17, 29, 62, 14 | | 14, 17, 23 | 22 | |
| 6.e. Colored bike lanes | 6, 11 | | | 4, 6, 8, 11, 27, 40 | | | | 4, 6, 11, 24, 32, 40 | 27 |
| 6.f. Combined bicycle and parking width | | 63 | | 74 | | | 34 | 20 | |
| 6.g. Buffered bike lanes | 10, 12 | | | 12, 29, 74 | | | 10 | 12, 72 | |
| 6.k. Contra flow bike lane | 37 | | | 37 | 68 | | | 37 | |
| 6.l. Cycle tracks | 10, 12, 13, 49, 52, 70 | | | 10, 12, 13, 49, 58, 60, 82, 83 | 52 | | 10, 52 | 12 | |
| 6.m. Raised bicycle lanes | 16 | | | 16 | | | | | |
| 6.n. Bicycle boulevards | 76, 77, 100 | | | 78, 100 | | | | | |
| 6.o. Bike lanes and diagonal parking | 37, 63 | | | 37 | | | | 37 | |
| 7.a. Paved shoulders | 18 | | | 14, 18 | | 84 | | 14, 18 | |
| 7.g. Lighting | | | | 84, 88, 89 | | | | | |
| 8.b. Rumble strips | | | 94 | 23 | | | | 23, 25 | |

**Note:** Numbers in cells of tables refer to publication number in list of research evaluations, Table 2-3.

It is likely that there have been other research evaluations of bicycle facilities in addition to those summarized here. Nonetheless, a reasonable conclusion from these studies is that field evaluations of a number of different design guidelines never have been completed and that additional field investigations are warranted. In addition, because of the existence of inconsistent or sometimes contradictory findings, ~~additional~~ studies of some types of facilities may be useful. Based on this assessment of the literature, it is clear that additional research evaluations are needed.

### 2.2.3 Complete Street Policies and Programs

Motivated both by growing interests in bicycling and walking and by unacceptably high rates of fatalities for bicyclists and pedestrians, transportation planners and engineers have devoted increasing efforts to providing safe and comfortable travel for all transportation users. Among other initiatives, state and local governments have adopted Complete Street policies and initiated related designs and programs to provide safe environments for bicyclists and pedestrians as well as drivers of motorized vehicles. Because many new bicycle facilities have been implemented in the context of Complete Streets initiatives, and because Complete Streets initiatives often raise concerns about traffic flows, consideration of designs included within Complete Streets initiatives is warranted.

The FHWA, state departments of transportation (DOTs), metropolitan planning organizations (MPOs), and many county and municipal governments are working to implement Complete Streets policies. Complete Streets policies and design manuals typically address a set of common factors, including traffic volumes and mode share, existing infrastructure, community desires, and available resources. The objectives of these policies are to support uncongested movement of all users while simultaneously reducing conflicts and increasing safety for all users.

With respect to bicycle facilities, a key objective of Complete Streets policies is to maximize safety. Safety is often achieved by separating different modes of travel to the extent possible in terms of both time and space. For instance, separating bicyclists from both vehicles and pedestrians or informing users about the presence and mix of travel modes both might be viable options to address the safety concerns of cyclists. However, finding solutions to address the inherent conflicts at intersections where cyclists cross paths with other modes of travel is more challenging. The studies summarized in Table 2-4 indicate three common approaches to addressing intersection safety: 1) establishing a goal to eliminate vehicle and bicycle conflicts without diminishing mobility or accessibility of all users, 2) reducing the number of conflict points to decrease the chances of collisions (i.e., when it is not possible to remove all conflicts), and 3) designing intersections in a way that less severe collisions occur. These approaches also are reflected in Complete Street policies and manuals adopted by various state, regional, and local agencies.

Table 2-5 presents the purpose of a small, but illustrative set of Complete Streets manuals, along with the types of bike facilities recommended in them to develop a safe, comfort, and convenient road for all road users. Table 2-6 illustrates the types of policies incorporated in Complete Streets documents adopted by state, regional, and local agencies in Minnesota. The goals and objectives of the Complete Streets initiatives summarized in Table 2-5 and 2-6 are related to the primary aim of this study, namely, to provide new, empirical evidence on the traffic impacts of bicycle facilities that designers and engineers can use to increase the efficiency and safety of our transportation systems.

**Table 2-5 Purpose of the Recent Published Complete Street Manuals**

| City | Year | Purpose | Bike Facilities |
|---|---|---|---|
| Louisville | 2007 | To develop a multimodal network that manages the demand for travel and improves the efficiency of the community's transportation system as envisioned in Cornerstone 2020. | shoulders, shared lanes, wide curb lanes, bicycle lanes, shared use paths, surfaces, interchange crossings, marking, bike lane with parking, signing, bike lane with bus stop, rumble strips, gutter pan. |
| Charlotte | 2007 | Providing the best possible streets to accommodate growth, transportation choices, and help keep Charlotte livable requires a different philosophy of planning and designing streets. | signing, bike lanes, pavement markings, street lighting, bike boxes, bike signals, buffers from travel lanes and parked cars, roundabouts, choker, speed humps. |
| Maricopa | 2011 | Increase in connectivity between travel modes, safety through reduction in vehicle, bicycle, and pedestrian crashes, transit ridership, access to adjacent uses, and compliance with speed limits | bicycle lanes and lane widths, bike box, physically separated bike lanes, shared lane marking, road diets, shared-use paths. |
| North Carolina | 2012 | To ensure that all streets are planned and constructed to support safety and mobility for all users. | bicycle lanes, shared-lane markings, signage, paved shoulders, elements at intersections, multi-use path, bike boxes, treatments for exclusive right turn lanes, mid-block crossings, roundabouts, curb lane, bridge, road diet. |
| Philadelphia | 2012 | Balance the needs of all users in planning, design, construction, maintenance, and operation;<br>Prioritize the safety of those traveling in the public right of way, and in particular the safety of children, the elderly, and persons with disabilities. | conventional bike lane, left-side bike lane, buffered bike lane, contra-flow bike lane, climbing bike lane, cycle track, shared-use path, marked shared lane, green colored pavement, bike route signs, bike boxes, raised crossings, two-stage left turn queue boxes, roundabouts, curb extensions. |
| Southern Nevada | 2013 | Every street and neighborhood is comfortable to walk and bicycle in.<br>Every child can walk or bike to school safely.<br>Seniors, children, and disabled people can cross all streets safely and comfortably.<br>There are zero traffic fatalities. | shared roadways, bicycle boulevards, paved shoulders, bike lanes, cycle tracks, shared use paths, bikeway markings, bike boxes, bicycle signal detection, two-stage turn queue boxes, colored pavement treatments. |
| Minnesota | 2013 | To ensure that facilities and designs promote health through physical activity and active transportation<br>or create streets that are safe for vulnerable travelers including children, older adults, and those with disabilities. | - |

**Table 2-6 Selected Minnesota Complete Streets Initiatives: Policies and Strategies**

| Agency | Policies and Strategies |
|---|---|
| MnDOT (2010) | • The commissioner shall address relevant protocols, guidance, standards, requirements, and training, and shall integrate related principles of context-sensitive solutions.<br>• Local road authorities are encouraged, but not required, to create and adopt complete streets policies for their roads that reflect local context and goals. |
| Fargo-Moorhead Metropolitan Council (2010) (MPO) | • Encourage project sponsors to consider bicyclists in the planning and design of all proposed transportation projects.<br>• Project sponsors are responsible for determining the most appropriate facility or combination of facilities for accommodating bicyclists of all ages and abilities.<br>• Provide alternate routes for bicyclists during construction,<br>• Reconstruction and repair of streets.<br>• Develop a traffic calming policy; or review existing policies or ordinances to ensure that consideration is given to various traffic calming techniques.<br>• Develop a schedule of regular pavement marking maintenance for on-road bicycle facilities.<br>• Reduce the number of travel lanes on roadways where appropriate to create more operating room for bicyclists and to improve vehicular flow for motorists. |
| Byron (2010) (municipality) | • Bicycle shall be included in street construction, re-construction, re-paving, and re-habilitation projects.<br>• The design of new or reconstructed facilities should anticipate likely future demand for bicycling and should not preclude the provision of future improvements.<br>• The City will develop implementation strategies that may include evaluating and revising manuals and practices.<br>• Integrating sidewalks, bike facilities, transit amenities, and safe crossing into the initial design of street projects avoid the expense of retrofits later.<br>• Improve the access and mobility for all users of streets in the community by improving safety through reducing conflict and encouraging non-motorized transportation. |
| Rochester (2009) (municipality) | • Bicycle shall be included in street construction, re-construction, re-paving, and re-habilitation projects.<br>• The design of new or reconstructed facilities should anticipate likely future demand for bicycling and should not preclude the provision of future improvements.<br>• The City will develop implementation strategies that may include evaluating and revising manuals and practices.<br>• Integrating sidewalks, bike facilities, transit amenities, and safe crossing into the initial design of street projects avoid the expense of retrofits later.<br>• Improve the access and mobility for all users of streets in the community by improving safety through reducing conflict and encouraging non-motorized transportation. |

## 2.3 THE NEED FOR FIELD EVALUATIONS OF BICYCLE FACILITIES

Several observations can be drawn from the preceding review:

- Demand is growing for information about the impacts of bicycle facilities, including both their effects on safety of cyclists and on conflicts with other users.
- Researchers have responded to this demand, the number of studies of the effects of bicycle facilities has grown recently, and this growth in research output is expected to continue.
- Many national, state, regional, and local agencies have prepared design manuals for bicycle facilities. While there is considerable overlap among manuals, new designs are being developed and deployed.
- Existing design manuals and guidance documents identify a wide range of designs that may be relevant depending on project objectives, context, and site characteristics. Based on categories included in the various manuals, these guidelines can be grouped in eight categories (Table 2-2):

    1. Traffic calming components;
    2. Signalization and marking;
    3. Geometric design components;
    4. Bikeway components;
    5. Intersection components;
    6. Cross-section components;
    7. Road design components;
    8. Separator components.

- Research or field evaluations were found for only about half of the design components included in the manuals and guidance documents. Some type of facilities (e.g., bicycle lanes) have been evaluated in multiple studies. In general, it appears the types of facilities studied most often include those most commonly installed (e.g., bicycle lanes, round-a-bouts), or those used in intersections where accidents are most likely to occur (e.g., bike boxes).
- Research evaluations of 33 different design components were not identified. It is likely that some of these designs (e.g., raised bicycle lanes, railroad crossings, crossing angle, choker entrances, lanes and turning movements, and bridge facilities) have been evaluated but that findings have not been reported in the peer-reviewed or catalogued literature. It also is likely that some of these designs never have been evaluated.
- Gaps in our knowledge of the traffic impacts of different designs can be inferred from the data in tables in this review. Table 2-2, for example, identifies which designs have been evaluated (i.e., those that are shaded) and those for which no evaluations were obtained (i.e., those without shading).

- A general approach used in field studies involves videotaping and analysis of bicycle-vehicle interactions in a pre-post or matched pair design. The method of reduction of video data depends on the study objectives.
- Although there appears to be a consensus of the effects of some types of facilities on safety of cyclists (e.g., multiple studies have found bike lanes increase safety by reducing encroachments), less is known about effects of facilities on vehicular traffic (e.g., in which contexts, if any, do bike lanes slow vehicular traffic and/or contribute to congestion).
- Many of the designs included in the guidance documents in this review have been implemented in Minnesota, and new designs are being deployed. For example, bicycle lanes exist in cities throughout the state, and the numbers of bicycle boulevards and green lane treatments are growing. There remain, however, few examples of cycle tracks or protected bike lanes.
- More studies have been completed on the effects of bicycle lanes than on other facilities such as sharrows, and the tradeoffs among alternatives with respect to driver behaviors typically have not been addressed in the same study.
- Comparatively few studies have focused on vehicle positioning when overtaking cyclists, congestion, vehicular speed, or displacement of vehicles to other roadways.

# CHAPTER 3: FIELD METHODS, SITE IDENTIFICATION, AND MONITORING APPROACH

The research team completed a pilot study to develop and demonstrate field methods that would be used to observe vehicle-bicycle interactions and evaluate the traffic impacts of different types of bicycle facilities. Following the pilot study, the research team collaborated with members of the TAP, MnDOT staff, and other local traffic engineers to identify sites for study. The pilot study was completed in the fall of 2014, and the study sites were selected in the spring of 2015.

## 3.1 PILOT STUDY TO DEMONSTRATE FIELD METHODS

### 3.1.1 Pilot Site Description

The location of the pilot site was a 2,500 foot section of Minnetonka Boulevard between McGinty Road and Williston Road, just west of I-494 in the city of Minnetonka, Minnesota (Figure 3.1). This site was suggested by a representative of Hennepin County who participated on the TAP. Minnetonka Boulevard is an arterial road with two travel lanes in each direction (i.e., four lanes total) with no shoulder on either side. The north side of the road includes a separated paved path, and the south side of the road includes a separated unpaved path. Figures 3.2 and 3.3 are pictures of the intersections that illustrate crossing patterns and include summaries of road geometry.

Figure 3.1 Pilot Deployment Site

Data were collected using cameras at each of the two intersections facing inward toward the midblock. The effective length of the observations is about 1000 feet at Williston and about 500 feet on McGinty. The latter is shorter because the objective was to cover the entire intersection. Figures 3.4 and 3.5 show views from each of the emplaced cameras.

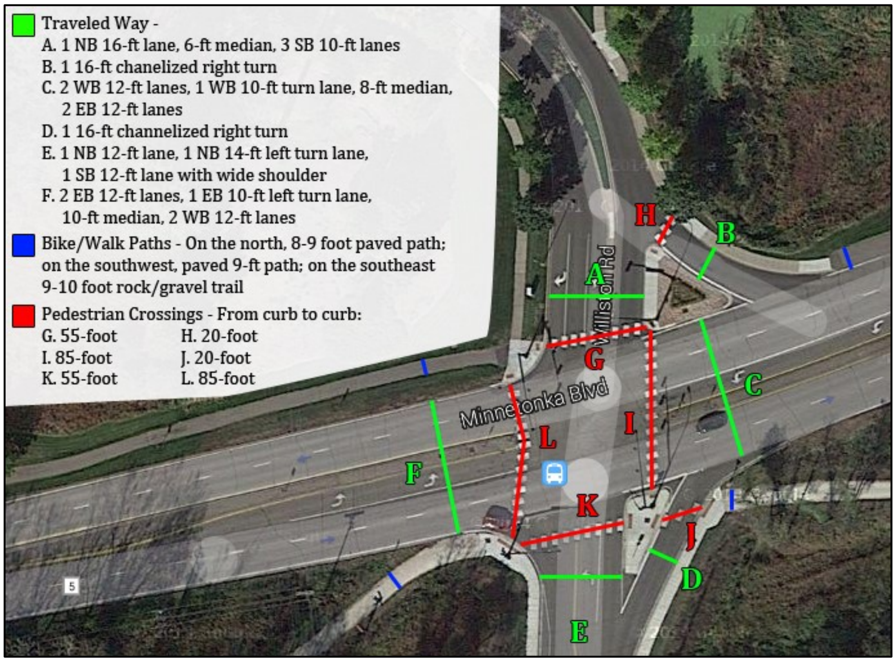


Figure 3.2 Intersection Detail and Measurements for Minnetonka Boulevard and Williston Road

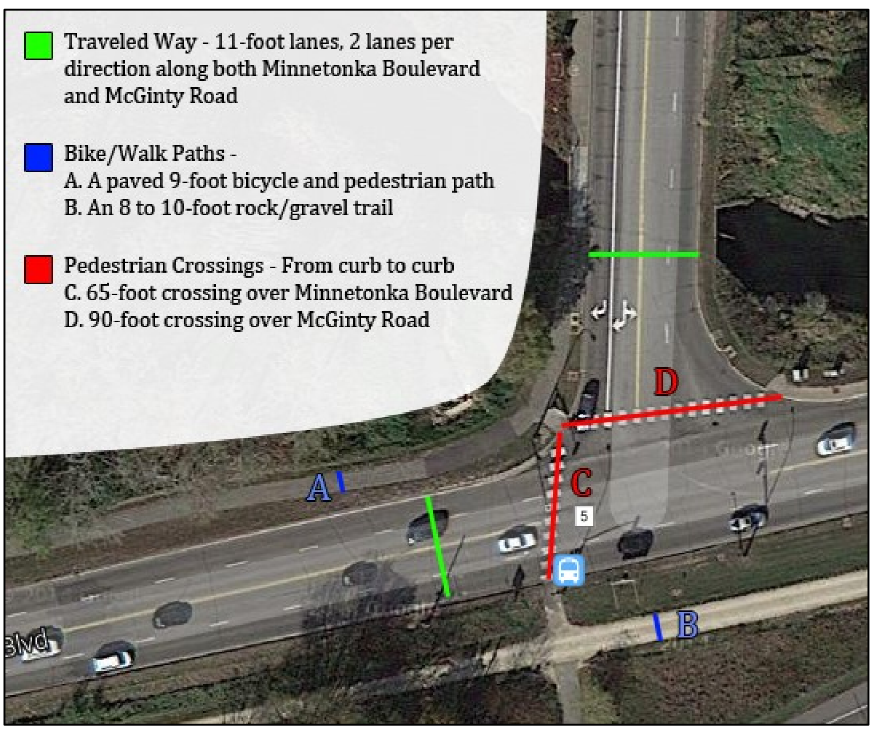


Figure 3.3 Intersection Detail and Measurements for Minnetonka Boulevard and McGinty Road


Figure 3.4 Camera View at McGinty Intersection

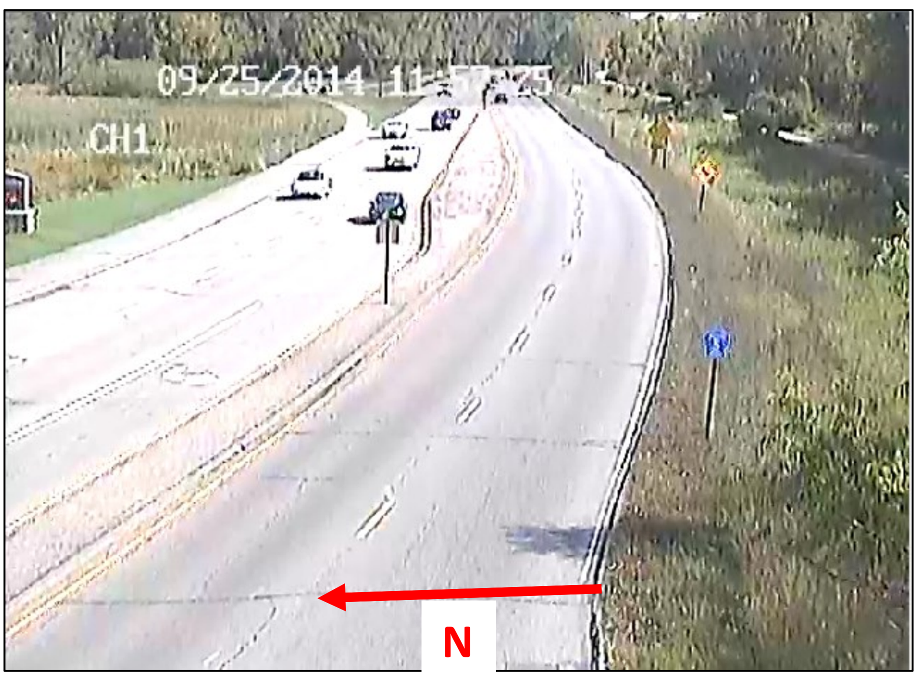


Figure 3.5 Camera View at Williston Intersection

### 3.1.2 Data Reduction

Video data were collected from Thursday, September 25th through Tuesday, September 30th, 2014 at the hours between 6:00 a.m. and 20:00 p.m. Because the purpose was to develop and demonstrate methodology only 30 of the 74 available hours of daylight video coverage were analyzed for each camera location. The time periods analyzed were:

- Thursday, 09/25/14: 12:45:59-20:00:00
- Friday, 09/26/14: 06:00:00-20:00:00 (8:00-9:00 incomplete due to video malfunction)
- Saturday, 09/27/14: 06:00:00-13:00:00

Because of the timing of sunrise and sunset, the pedestrian paths were not visible until 6:30 a.m. or after 19:30 p.m.; only bicyclists with proper head and/or tail lights were observed and counted within those time frames.

### 3.1.3 Data Reduction Methodology

The initial data reduction focused on parameters relevant to detecting bicycle interactions with traffic. These included: bicycle location, vehicle speed changes, interactions such as lane changes or encroachments into oncoming lanes, and any resulting conflicts. A brief definition of each follows:

- *Bicycle location:* Whether the bicyclist utilized bike paths or rode on the street, and where they were positioned on the street. Bicycle positioning at the McGinty intersection was categorized by those travelling East-bound or West-bound on designated paths parallel to the road, those crossing Minnetonka on the crosswalk, and those travelling in any direction on the street itself. Positioning at the Williston intersection was categorized by those travelling East-bound or West-bound on the designated path South of Minnetonka, those travelling East-bound or West-bound on the designated path North of Minnetonka, and those travelling in either direction on the street itself. For those bicycles riding in the street, their approximate distance away from the curb was noted.
- *Speed change:* Whether a vehicle speeds up when overtaking a bicycle, or slows down upon approaching one. The original objective was to make these determinations from observations of vehicles in the video. The observers were unable to make these types of determinations reliably. The only observable change in speed involved vehicles that noticeably hit the brakes to avoid passing a bicyclist in their lanes and then allowed one or more vehicles to pass before merging into the adjacent lane. No conflicts or congestion resulted from any such scenario in the tape that was reviewed. .
- *Lane changes:* Whether one or more vehicles change lanes upon approaching an on-road bicyclist.

- *Lane Encroachment:* Whether a vehicle passing an on-road bicyclist crosses into the adjacent traffic lane.
- *Conflict:* Any “out of the ordinary” or unexpected vehicle or bicyclist behavior that may cause a safety concern. Unique interactions were logged directly to reduce ambiguity. The only conflict observed resulted from a vehicle blocking the pedestrian crosswalk, forcing the bicyclist to pass behind the vehicle as other vehicles approached from a significant distance away.

### 3.1.4 Results of the Pilot Study

Table 3-1 summarizes data collected from the Williston intersection. Hennepin County was interested in whether or not cyclists utilizing the North side path had any effect on vehicles travelling in the lane closest to the path. The travel of bicyclists on the parallel bike paths therefore was separated by direction. Students reviewing the video tape counted 481 bicyclists on the South side path and 27 bicyclists on the North side path. No deviations of any kind were observed by motor vehicles in this situation. The students counted 77 bicyclists on the roadway. Twenty vehicles passing bicyclists (26% of the cyclists) changed lanes (i.e., made full passing maneuvers), and 11 vehicles (14% of the cyclists) encroached into the adjacent travel lane when passing. Seven vehicles passing cyclists (9% of the cyclists) appeared to slow before merging into the adjacent lane, but these observations are not considered reliable.

Table 3-2 summarizes results from the McGinty intersection. The direction of travel was indicated, as well as turning direction through the intersection if relevant. Students counted 429 bicyclists on the paths running East and West bound along Minnetonka Blvd; of these, 157 bicyclists used the N-S crosswalk across Minnetonka Blvd.  The students counted 120 bicyclists on the roadway. Sixteen vehicles passing bicyclists (13% of cyclists) changed lanes, while 10 (8% of cyclists) encroached into the adjacent lane.

**Table 3-1 Williston Intersection Data Summary**

| | | | Vehicle Behavior | | |
|---|---|---|---|---|---|
| **Location** | **Count** | **Conflicts** | **Lane Changes** | **Encroachments** | **Slowing** |
| North Side Path | 27 | 0 | 0 | 0 | 0 |
| South Side Path | 481 | - | - | - | - |
| Street | 77 | 0 | 20 | 11 | 7 |
| *Total Observed* | *585* | | | | |

**Table 3-2 McGinty Intersection Data Summary**

| Location | | Count | Conflicts | Disobey Signal | Vehicle Behavior<br>Lane Changes | Encroachments | Slowing |
|---|---|---|---|---|---|---|---|
| Paths | | 429 | - | - | - | - | - |
| Crosswalk | Northbound | 70 | 0 | 4 | - | - | - |
| | Southbound | 87 | 1 | 3 | - | - | - |
| Street | | 120 | 0 | 3 | 16 | 10 | 3 |
| *Total Observed* | | *706* | | | | | |

Three general observations about observing bicycle-vehicle interactions were drawn from the pilot study:

1. When observing vehicles are overtaking bicyclists on a roadway, students can reliably document vehicular lane changes and vehicular encroachment into adjacent lanes.
2. When observing vehicle-bicycle interactions on video tape, students cannot reliably document changes in vehicle speed. Although students sometimes can observe brake lights when drivers slow, other changes in speed, including gradual slowing in anticipation of overtaking or speeding to change lanes cannot be reliably determined.
3. Without computer-assisted analyses of video tape, the only reliable observations that can be made include lane changes, lane encroachment, and queuing behind cyclists.

Three specific observations about bicycle-vehicle interactions on Minnetonka Boulevard were drawn from the pilot study:

Vehicles do not appear to be affected by cyclists in the shared-use paths adjacent to, but separated from, Minnetonka Boulevard.

Between 13% and 17% of bicyclists chose to ride on Minnetonka Boulevard despite the availability of a shared use path adjacent to the roadway. This observation is evidence some cyclists prefer on-street cycling to cycling on separated paths.

Between 24% and 49% of the bicyclists were overtaken by vehicles that changed lanes, encroached into the adjacent lane, or appeared to slow when interacting with the bicycle. These maneuvers by drivers were legal and were not associated with dangerous conflicts. One factor that mitigated these effects is that the roadway was not operating at capacity. Despite this fact, these maneuvers are examples of impacts of bicycle facilities on traffic flows that warrant consideration. The percentage of interactions that involved these maneuvers likely was increased because there are no shoulders along this section of Minnetonka Boulevard.

## 3.2 SELECTION OF STUDY SITES

Based on findings from the literature review, the research team worked with members of the TAP and local engineers to identify sites for study. Most sites were selected because local engineers were interested in the effects of facilities at specific locations. Consideration of local priorities resulted in selection of several sites with bicycle lanes and sharrows, both of which have been previously studied. The research design enabled comparison of interactions and effects on driver behavior and traffic both within and across study locations.

Nine sites were included in the study (Table 3-3). The sites are located in Duluth, Mankato, Minneapolis, and St. Paul and include three arterials, four major collectors, and four urban local roads. Across the nine locations, road widths range from 32 feet to 66 feet; the number of lanes ranges from two to six. Across the sites, vehicular average annual daily traffic (AADT) ranges from an estimated 2,476 to 21,500. The types of bicycle facilities varies across the sites and includes travel lanes without bicycle facilities, designated shared lanes, striped bicycle lanes, buffered bicycle lanes, and a shared-use path. Investigations at one site (i.e., Mankato) included a pre-post assessment of a new bicycle facility. At other locations, (e.g., Marshall Avenue; St. Paul, Como Avenue; Minneapolis) different types of facilities exist on traffic lanes going in opposite directions, enabling interesting within-site comparisons.

## 3.3 DATA COLLECTION, REDUCTION, AND ANALYSIS

The research team followed standard procedures used in observational studies of traffic. Specific steps included:

- Deployment of cameras and video collection
- Review and initial video reduction
- Manual observation and bin counts
- Additional video reduction
- Creation of movement log and classification of interactions
- Analysis of interactions

### 3.3.1 Camera Deployment

Cameras were deployed at each location to capture a view of cyclists and drivers for as much roadway as possible. Cameras were set to record during daylight hours. Table 3-4 summarizes numbers of days cameras were in the field at each site, the hours of video taken, the hours of video observed for quality checks, and the hours of video processed for the movement log. The duration of taping varied across locations and ranged from 5 days to 51 days. The hours of video taken also varied over an order of magnitude, ranging from 65 to 623. Across sites, the hours of video processed for the bin count ranged from 48 to 570. The hours of tape reduced for the movement logs, which form the core of the study, ranged from 16 to 307.

Views from each camera at each location are presented in Chapter 4 along with results. Each camera was deployed to maximize the viewing range, but site characteristics varied somewhat, restricting the length of views at some locations. The principal effect of these variations is related to the hours of video processed for the movement log. All else equal, fewer interactions would be recorded in video at locations where the length of view is shorter. Because the goal was to obtain at least 200 unique bikers at each site, where each biker interacts with at least one vehicle, this variation is believed to have no effects on the substantive analyses.

**Table 3-3 Summary of Site Characteristics (2 pages)**

| Study Location | | Street Functional Classification | MnDOT Estimated AADT 2-Day Average Counts from collected video | Road Geometry & Speed Limit | Facility 1 – Bike Lanes | Facility 2 – Shared Lanes |
|---|---|---|---|---|---|---|
| Veteran's Bridge, Mankato MN (44.169344, -94.003479) | Before | 3 – Principal Arterial | • 21500 (2013)<br>• 19012 (Apr-2015, 2-day Avg. 6:00-20:00) | • Road width: 44ft<br>• Lanes: 3WB-12ft (2Thru, 1Aux), 3EB-12ft (1LT, 1Thru, 1RT)<br>• Concrete raised median<br>• 30 mph (posted) | Quasi-bike lane<br>• Fog line<br>• Adjacent to sidewalk (6ft)<br>• Width: 6ft<br>• Tapers to 6ft starting ~200ft from intersection[1] | |
| | After | | • 21500 (2013)<br>• 15569 (Sep-2015, 2-day Avg. 7:00-18:00) | • Road width: 38ft<br>• Lanes: 3WB-11ft (2Thru, 1Aux), 3EB-11ft (1LT, 1Thru, 1RT)<br>• Concrete raised median<br>• 30 mph (posted) | | Shared lane<br>• Fog line marks shoulder<br>• Adjacent to signed shared-use path (sidewalk)<br>Width: Path=12ft, Shoulder=2ft |
| Marshall Avenue, St. Paul MN (44.948444, -93.192352) | | 4 – Minor Arterial | • 18100 (2013)<br>• 15800 (Aug-2015, 2-day Avg. 7:00-18:00) | • Road width: 66ft<br>• Lanes: 4 (2 WB, 1WB Left, 1 EB)<br>• Raised median with vegetation, turn lanes<br>• 30 mph (posted) | Striped bike lane (Eastbound)<br>• Bike lane width: 6ft<br>• Travel lane width: 13ft[2]<br>• Parking? Yes/No* | Shared lane (Westbound)<br>• No street markings<br>• Traffic signs authorize bikes to take lane<br>• Travel lane width:<br>○ Left: 11ft<br>○ Right:13ft (11ft asphalt, 2ft gutter) |
| Como Avenue, Minneapolis | | 5 – Major Collector | • 12100 (2013)<br>• 7900 (Mar-2016, 2-day Avg. 6:00-18:00) | • Road width: 45ft<br>• Lanes: 2 (1EB, 1WB)<br>• Parking both sides, multiple driveways<br>• 30 mph (posted) | Striped bike lane (Westbound)<br>• Bike lane width: 6ft.<br>• Weathered lane markings<br>• Travel lane width: 11ft | Shared lane (Eastbound)<br>• Sharrows<br>• Travel lane width: 20ft/13.5ft[3] |

| | | | | | |
|---|---|---|---|---|---|
| (44.987893, -93.228205) | | | | • Parking: Yes | |
| 15th Ave SE, Minneapolis MN (44.982907, -93.232054) | 5 – Major Collector | • 11500 (2013)<br>• 8053 (May-2016, 2-day Avg. 6:00-19:00) | • Road Width: 36ft<br>• Lanes: 2 (1NB, 1SB)<br>• No Parking on either side<br>• 25 mph (posted) | Buffered Bike Lanes<br>• Buffered Bike Lane (6ft + 1ft Buffer)<br>• Travel lane width: 11ft | |

### Table 3-3 Summary of Site Characteristics (Continue)

| Study Location | Street Functional Classification | MnDOT Estimated AADT<br>• 2-Day Average Counts from collected video | • Road Geometry | Facility 1 – Bike Lanes | Facility 2 – Shared Lanes |
|---|---|---|---|---|---|
| N Washington Ave, Minneapolis MN (44.988330, -93.277853) | 4 - Minor Arterial | • 14800 (2014)<br>• 10032 (Nov-2015, 2-day Avg. 7:00-17:00) | • Road Width: 68ft<br>• Lanes:3 (1 EB, 1 WB, 1 CLT)<br>• Parking on both sides<br>• 30 mph (posted) | Double Buffered Bike Lane<br>• Parking: 6ft<br>• Buffered Bike Lane 10ft (6ft + 2ft Buffer both sides)<br>• Travel lane width: 11ft | |
| S Wayzata Blvd, Minneapolis MN (44.969905, -93.315383) | Urban Local Road | • ADDT NA<br>• 5980 (Oct-2015, 2 day Avg. 5:00-18:00) | • Road Width: 32ft<br>• Lanes:2<br>• No Parking on either side<br>• 30 mph (posted) | Bike Lane (post-construction)<br>• Bike Lane Width: 6ft<br>• Travel lane width: 10ft | Shared Lane (pre/during construction)<br>• No Lane Markings[4]<br>Travel lane width: 16ft |
| UMN, Pleasant St SE Minneapolis MN (44.975937, -93.236874) | Urban Local Road | • ADDT NA<br>• 2476 (May-2015, 2 day Avg. 5:00-19:00) | • Road Width: 34ft<br>• Lanes: 2 (1NB, 1SB)<br>• Heavy Bus traffic<br>• 20 mph (posted) | Striped bike lane<br>• Travel Lane: 11ft<br>• Parking: 6ft | |

| | | | | | |
|---|---|---|---|---|---|
| E Superior St Duluth MN (46.792402, -92.091129) | Urban Local Road | • 10800 (2014)<br>• 7853 (Sep-2015, 2 day Avg. 6:00-18:00) | • Road Width: 35ft<br>• Lanes: 2 (1EB, 1WB)<br>• Parking on west side<br>• 30 mph (not posted) | | No signed bike facility<br>• Travel Lane: 13ft<br>• Parking: 9ft |
| Kenwood Ave Duluth MN (46.821591, -92.100451) | Urban Local Road | • 11100 (2012)<br>• 10878 (May-2015, 2 day Avg. 7:00-19:00) | • Road Width: 44-50ft<br>• Lanes: 4 (2NB, 2SB)<br>• No Parking on either side<br>• 30 mph (posted) | | Shared Lane<br>• Sharrows (in right most lanes)<br>• Travel Lane: 11ft |

[1]Bike lane shift starting. Parking begins after intersection seen in video

[2]Travel lane is merging from 2 lanes to single lane in frame. After the intersection the lane is 13ft

[3]Includes parking generally (from satellite pictures) 13.5ft from center dash to the edge of parked vehicles

[4]Road was under construction so no lane markings of any kind were present

**Table 3-4 Summary of Field Observations**

| Study Location | | Camera | Video Recording Period | Hours of Video Taken | Hours of Video Processed for Bin Count | Hours of Video Processed for Movement Log |
|---|---|---|---|---|---|---|
| Veteran's Bridge, Mankato MN (44.169344, -94.003479) | Before | Charlie | • 7:00am – 8:00pm<br>• 34 Days | 395.25 | 388.75 | 264 |
| | After | Delta | • 7:00am – 7:00pm<br>• 28 Days | 328 | 307.5 | 307.5 |
| Marshall Avenue, St. Paul MN (44.948444, -93.192352) | | Bravo | • 7:00am – 7:00pm<br>• 19 Days | 220 | 135 | 31 |
| | | Delta | • 7:00am – 7:00pm<br>• 19 Days | 220 | 203 | 42 |
| | | Charlie | • 7:00am – 7:00pm<br>• 18 Days | 208 | 190 | 48 |
| Como Avenue, St. Paul MN (44.987893, -93.228205) | | Alpha | • 6:00am – 6:00pm<br>• 5 Days | 65 | 48 | 37 |
| | | Delta | • 6:00am – 6:00pm<br>• 12 Days | 116 | 116 | 78.5 |
| 15th Ave SE, Minneapolis MN (44.982907, -93.232054) | | Bravo | • 6:00am – 6:00pm<br>• 41 Days | 494 | 491 | 22 |
| | | Charlie | • 6:00am – 6:00pm<br>• 51 Days | 623 | 570 | 16 |
| N Washington Ave, Minneapolis MN (44.988330, -93.277853) | | Bravo | • 5:00am – 5:00pm<br>• 23 Days | 287 | 269 | 60 |
| | | Charlie | • 5:00am – 5:00pm<br>• 25 Days | 301 | 282 | 45 |
| | | Delta | • 5:00am – 5:00pm<br>• 23 Days | 283 | 157 | 120 |
| UMN, Pleasant St SE Minneapolis MN (44.975937, -93.236874) | | Alpha | • 6:00am – 7:00pm<br>• 13 Days | 176 | 157 | 46 |
| E Superior St Duluth MN (46.792402, -92.091129) | | Echo | • 6:00am – 6:00pm<br>• 34 Days | 302 | 283.5 | 195 |
| | | Foxtrot | • 6:00am – 6:00pm<br>• 34 Days | 302 | 288 | 249 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Kenwood Ave Duluth MN (46.821591, -92.100451) | | Foxtrot | • 7:00am – 7:00pm<br>• 37 Days | 444 | 430 | 315 |
| S Wayzata Blvd, Minneapolis MN (44.969905, -93.315383) | Phase 1 | Echo | • 5:00am – 6:00pm<br>• 8 Days | 110.5 | 110.5 | 110.5 |
| | Phase 2 | Echo | • 5:00am – 6:00pm<br>• 6 Days | 81 | 81 | 81 |
| | Phase 3 | Echo | • 5:00am – 6:00pm<br>• 16 Days | 222 | 222 | 222 |

### 3.3.2 Review and Initial Video Reduction

The video was retrieved from the field and manually reviewed to determine suitability for analysis. Observers identified periods of lost data due to malfunctioning equipment and periods with poor quality images that could not be analyzed. For example, poor weather or lighting conditions sometimes made accurate observation and counting of vehicle and bicycle movements impossible. This initial video reduction reduced the total amount of video available for analysis by 10-20% (Table 3-2).

### 3.3.3 Manual Observation and Bin Counts

Observers watched the video to obtain 15-minute bin counts of cyclists, vehicles, and pedestrians by direction and travel lane. The purposes of the bin counts were to characterize traffic volumes at each site and to identify subsets of video for more detailed analysis in the next round of observation and reduction. These bin counts were used to determine average hourly cyclist traffic at all sites and to characterize the shift in cyclist lane choice at the Mankato site. Observers also noted where cyclists and drivers occupied the frame together. Researchers defined any time when a bicycle and vehicle were in frame together and there was potential for their behavior to be affected as a "potential interaction."

### 3.3.4 Further Video Reduction

Because of the time required to manually observe and analyze traffic interactions, not all tape was analyzed.  Each site varied in volumes of cyclists, pedestrians, and vehicles, the numbers of times cyclists and drivers occupied frames simultaneously, and numbers of potential interactions. To optimize time, yet have an adequate subset of data to analyze, a smaller portion of video was chosen to be analyzed in depth. A target of at least 200 total individual cyclists with potential interactions was established. Days with typical conditions were chosen (e.g., limited rainfall, no unusual occurrences like lane closures), and all 11-12 hours of daylight video were watched for the chosen days. The analyses thus include both peak-hour and non-peak periods. Time of day for specific interactions was not analyzed. The period of time required to obtain a sufficient number of observations for analysis varied greatly across all sites. All results from the movement logs are based on these observations.

### 3.3.5 Movement Log and Classification of Interactions

The first step in creating the movement logs was to identify cyclists who had the potential to interact with a vehicle. As noted, if a cyclist occupied the same frame as a vehicle and their actions could possibly affect the drivers' behavior, or vice versa, the observation was considered a potential interaction. If a cyclist passed through the screen without encountering a vehicle, they were not coded in the movement log.

The potential interactions included the first frame the cyclist was seen (the entrance frame), any actions the bicycle took while in the frame, and any interactions with vehicles. This method of classification included some actions that were not direct interactions. For example, if a potentially interacting cyclist stopped because of a mechanical problem with a bike, but this stop had nothing to do with the nearby vehicle, this was recorded in the log, but later filtered out.

Each individual cyclist, or group of cyclists acting cohesively as a platoon, was assigned an arbitrary, unique identifying number. Their actions and the actions of the vehicle(s) in adjacent travel lanes then were coded in the movement log under their identifier, such that each cyclist could have anywhere from one to an infinite amount of actions or interactions with vehicles.

These records were consistent among all sites, and included the following information:

- Date = Date from timestamp in the video frame
- File Name = Video file name
- Direction = The direction of the road the cyclist is on (EB/WB or NB/SB)
- Cyclist = The direction the cyclist was physically heading (can be different from "direction")
- Cyclist # = An arbitrary number that is unique to every cyclist/cyclist group
- # in Group = The number of cyclists in a group and acting, more or less, as one unit
- Enters Frame (1/0) = A binary answer as to whether or not a record is that of an entrance frame (first frame of video the cyclist is seen in, 1 = yes, 0 = no)
- Time = Time from the timestamp
- Bike Lane = The lane the cyclist is in according to the key
- Bike Action = The action being taken by the cyclist according to the key
- Lane 1 Action = The vehicle action being taken in lane 1 while in the vicinity of the cyclist according to the key
- Lane 2 Action = The vehicle action being taken in lane 2 while in the vicinity of the cyclist according to the key
- Lane Queue = The number of cars queued up behind the cyclist (if in a main travel lane)
- Extra Comments = Any additional comments from the data reduction team

In the movement log, all bike and vehicle actions at each site were coded using the same key (Figure 3.6).

| Key: | | | |
|---|---|---|---|
| Bike lane (Initial bike location) | Bike Action | Vehicle Action per lane | Lane Speed Change |
| -1 - Sidewalk | 0 - No Action | -1 - No vehicle | 0 - No significant speed change |
| 0 - shoulder | 1 - To Lane 1 | 0 - No deviation while overtaking | 1 - Brake Lights |
| 1 - Lane 1 | 2 - To Lane 2 | 1 - To Lane 1 | 2 - Apparent slow down (no brake lights) |
| 2 - Lane 2 | 3 - To Lane 3 | 2 - To Lane 2 | 3 - Apparent Acceleration |
| 3 - Lane 3 | 4 - To Lane -1/Sidewalk | 3 - To Lane 3 | |
| 4 - On line between shoulder/ 1 | 5 - To Lane 0/Shoulder | 4 - Deviate within Lane (Left) | |
| 5 - Side Street | 6 - Crossed street | 5 - Encroach (Left) | |
| 10 - Cluster does not fit in lane | 7 - Biker Walking Bike | 6 - Deviate to adjacent lanes and back (Full lane Change/Passing) (Left) | |
| | 8 - Deviate within Location | 7 - Vehicle queues behind bike | |
| | 9 - Deviate to adjacent lanes | 8 - Deviate within Lane (Right) | |
| | 10 - Cluster does not fit in lane | 9 - Deviate partially into adjacent lane (Right) | |
| | 11 - Bike passing another in lane | 10 - Deviate to adjacent lanes and back (Full lane Change/Passing) (Right) | |
| | 12 - Adjacent road left turn | 11 - Stopped | |
| | 13 - Adjacent road right turn | 12 - Yield Left Turn | |
| | 14 - Stopped | 13 - Yield Right Turn | |
| | 15 - Runs Red | 14 - Vehicle crosses in front of slow moving/stopped biker | |
| | 16 - Biker moves around stopped car | | |

**Figure 3.6 Movement Log Key (for all sites)**

The analyses of the driver behaviors and potential traffic impacts of vehicle-bicycle interactions focused on vehicle movements with the potential to slow traffic and create congestion or to increase the risk of a crash. We focused on the results for specific outcomes of interactions that represent a continuum from no observable effect to vehicle queuing behind a bicycle (Figure 3.6):

- 0 - No deviation while overtaking,
- 4 - Deviation within lane (Left),
- 5 - Encroachment into adjacent travel lane (Left),
- 6 - Deviation to adjacent lanes and back (full lane change/passing)(Left)
- 7 - Vehicle queues behind bike.

Observers defined action 0 (no deviation) as the vehicle overtaking the cyclist without changing its travel path or speed in any discernable way. Action 4 (deviation within lane) was defined as moving left up to but not crossing into the adjacent lane while overtaking the cyclist. Action 5 (encroachment into adjacent travel lane) was defined as crossing no more than half a vehicle's width into the adjacent lane while overtaking before moving back into their original lane. Action 6 (deviation to adjacent lanes and back) was defined as a full passing analogous to driver decisions when passing a vehicle. Action 7 (vehicle queues behind bike) was defined as the vehicle following the cyclist. If additional vehicles queued behind the originally coded vehicle, the number of queued vehicles was noted in the movement log under "Lane Queue". Some other actions were observed and recorded (e.g., vehicles passing on the right if a cyclist was in a left travel lane), but these events were rare, and our analyses do not focus on them.

Manual observation requires use of professional judgment in classification and coding. To control for variation among observers, the supervisor periodically reviewed classifications, noted inconsistencies, and took action to ensure consistent coding. Although an initial objective was to document changes in vehicular speed, this proved impossible to measure visually, and coding was abandoned. Future analyses using automated process may provide insight into the prevalence of this outcome.

### 3.3.6 Analysis of Interactions

Researchers queried the movement log to extract potential interactions. This step further reduced the number of cases at each site to be analyzed and ensured that we were only examining events where bicycles and vehicles occupied the same frame with the potential to affect one another's behavior. This allowed us to determine the direct impact, if any, cyclists were having on traffic flow.

As noted, observers coded interactions until samples large enough for analysis at each were obtained. Thus, not all the potential interactions were analyzed. The analysis of key measures (e.g., no deviation, queuing) consists mainly of comparing frequencies of outcomes where vehicles overtook cyclists across treatment types.

# CHAPTER 4: BICYCLE-VEHICLE INTERACTIONS AND DRIVER BEHAVIORS ON ROADWAYS

Observed driver behaviors for all interactions are summarized by site in Table 4-1. We first present results by city and site. We then present and compare results by type of facility.

## 4.1 VETERAN'S MEMORIAL BRIDGE, MANKATO

The Veteran's Memorial Bridge site included pre-post analysis of infrastructure improvements, including changes in lane configuration, to increase safety for bicycle and pedestrian traffic. The roadway is a principal arterial with an estimated AADT of 21,500 (Table 3-3). The reconstruction project involved narrowing the vehicular travel lanes from 12 to 11 feet and widening existing six-foot sidewalks into 12-foot shared-use paths for both cyclists and pedestrians. The objective was to encourage bicyclists to move from the travel lanes on the bridge to the shared-use path. Pre-construction bicycle facilities consisted of in-street 6-foot quasi-bike lanes (a shoulder with a fog line adjacent to travel lanes) running EB and WB, and post-construction removed them for 3-foot shoulders with no marked bicycle facility and the new shared-use path. The same treatments were implemented on both sides of the roadway. Photos A and B show the configuration of the travel lanes and bicycle facilities pre- and post-construction, respectively.

### 4.1.1 Effects of Reconstruction on Riding Location

The results show cyclists have shifted from the quasi-bike lanes adjacent to the travel lanes and are using the shared-use paths as intended. In the pre-construction period, approximately 37% of EB cyclists and 27% of WB cyclists, respectively, were using the shoulder (Table 4-2). These percentages dropped substantially with the construction of the shared-use paths in each direction. Post-construction, less than 12% of cyclists traveling EB or WB chose to ride in the 3-foot shoulder adjacent to the right travel lane. Prior to construction, the majority of bicyclists were on a six-foot wide sidewalk, causing conflicts with pedestrians. Observers noted that potentially hazardous interactions between bicyclists and pedestrians on the sidewalks seemed to occur less frequently post-construction, although no formal counts of these interactions were taken.

### 4.1.2 Effects of Reconstruction on Bicycle-vehicle Interactions.

The proportion of bicycle-vehicle interactions that resulted in changes in driver behavior increased following reconstruction (i.e., reduction of the shoulder marked with a fog line from six to three feet and widening of the 6 foot sidewalk to 12 feet; Table 4-1). During the pre-construction phase, 71% of vehicles overtaking bicycles in the EB six-foot quasi-bicycle lane maneuvered to increase distance between the vehicle and cyclist when passing. In the post-construction period, 97% maneuvered to increase distance when overtaking cyclists on the 3-foot wide shoulder. The pre-post change in interactions on the WB direction was consistent, increasing from 93% to 97% of vehicles maneuvering or queuing when overtaking a cyclist. These increases in the percentages of vehicles that deviated or queued suggest that the reduction in width of the shoulder was a causal factor (Table 4-1).

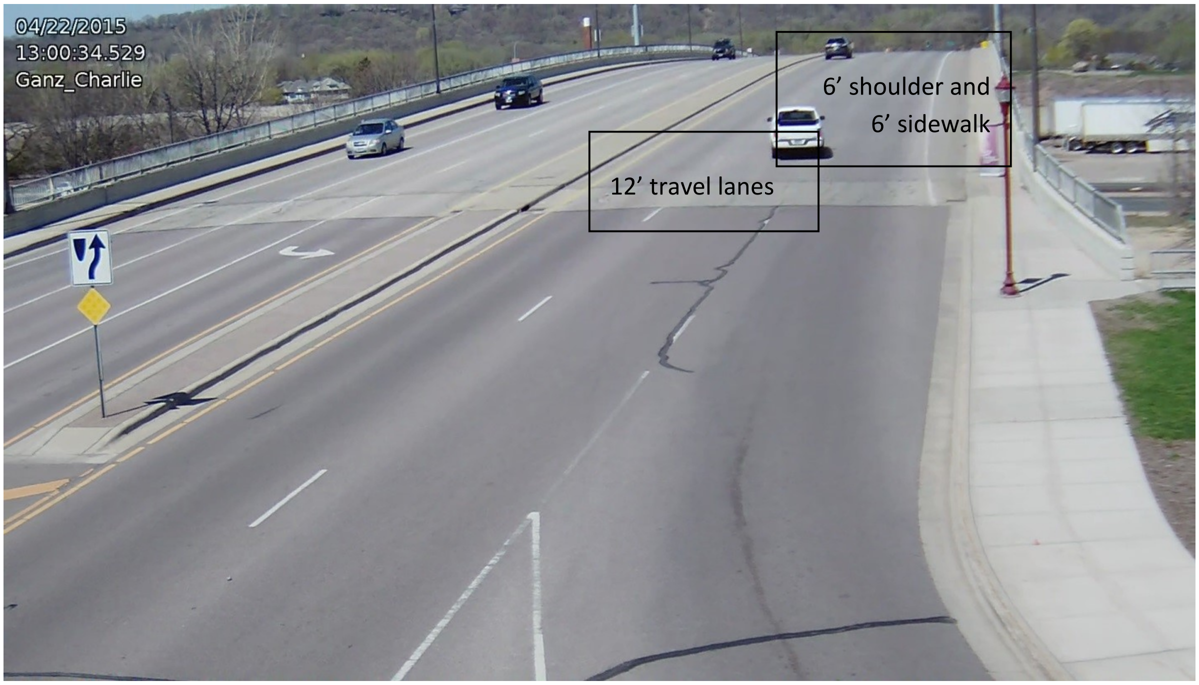


**Figure 4.1 Mankato Study Site: Pre-Construction**


**Figure 4.2 Mankato Study Site: Post-Construction**

### Table 4-1 Driver Behaviors in Vehicle-driver Interactions (3 pages)

| Percent of Total Interactions | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0% | | | | | | 50% | | | | | | 100% |

| Study Location | | Camera | Type of Facility | Direction | Biker in facility with selected interactions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Interactions | No vehicle deviation (%) | Deviation in lane when overtaking (%) | Encroachment in adjacent lane when overtaking (%) | Full lane change into adjacent lane when overtaking (%) | Vehicle queued behind cyclist (%) |
| Veteran's Bridge, Mankato MN (44.169344, -94.003479) | Before | Charlie | Wide Shoulder | EB | 365 | 28.5% | 55.6% | 15.3% | 0.0% | 0.6% |
| | | | Wide Shoulder | WB | 305 | 7.2% | 65.9% | 20.3% | 5.6% | 1.0% |
| | After | Delta | Narrow Shoulder | EB | 238 | 3.4% | 23.1% | 57.1% | 10.9% | 5.5% |
| | | | Narrow Shoulder | WB | 139 | 2.9% | 33.8% | 41.7% | 8.0% | 3.6% |
| Marshall Avenue, St. Paul MN (44.948444, -93.192352) | | Bravo | Bike Lane | EB | 620 | 77.1% | 21.9% | 0.8% | 0.0% | 0.2% |
| | | | Shared Turn Lane | WB Lane 2 (Through) | 70 | 40.0% | 1.4% | 1.4% | 0.0% | 57.1% |
| | | Delta | Wide Shoulder | EB | 1324 | 58.6% | 29.4% | 8.6% | 1.3% | 2.1% |
| | | | Wide Shoulder | WB | 1032 | 84.3% | 13.2% | 2.5% | 0.0% | 0.0% |
| | | Charlie | Bike Lane | EB | 1366 | 95.0% | 4.9% | 0.1% | 0.0% | 0.0% |
| | | | Shared Lane (Signed) | WB Lane 1 (shared) | 67 | 7.5% | 1.5% | 11.9% | 6.0% | 73.1% |
| | | | Adjacent Thru Lane | WB Lane 2 | 256 | 97.3% | 2.0% | 0.4% | 0.4% | 0.0% |
| | | Alpha | Bike Lane | EB | 292 | 49.0% | 33.6% | 15.8% | 1.7% | 0.0% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Como Avenue, Minneapolis MN (44.987893, -93.228205) | | Sharrows | WB | 417 | 20.1% | 33.6% | 29.3% | 14.6% | 2.4% |
| | Delta | Faded Bike Lane | EB | 772 | 76.4% | 11.0% | 3.1% | 0.0% | 9.5% |
| | | Sharrows | WB | 1091 | 55.9% | 5.6% | 7.3% | 1.0% | 30.2% |

**Table 4-1 Driver Behaviors in Vehicle-driver Interaction (Continue)**

| Study Location | | Camera | Type of Facility | Direction | Biker in facility with selected interactions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Interactions | No vehicle deviation (%) | Deviation in lane when overtaking (%) | Encroachment in adjacent lane when overtaking (%) | Full lane change into adjacent lane when overtaking (%) | Vehicle queued behind cyclist (%) |
| 15th Ave SE, Minneapolis MN (44.982907, -93.232054) | Pre - Construction | Bravo | Bike Lane | NB | 1282 | 14.4% | 79.4% | 3.5% | 0.0% | 2.7% |
| | | | Bike Lane | SB | 2495 | 23.9% | 72.1% | 1.6% | 0.0% | 2.3% |
| | Construction | | Shared Lane (Signed) | NB | 204 | 2.9% | 10.3% | 16.2% | 2.9% | 67.7% |
| | | | Shared Lane (Signed) | SB | 685 | 1.0% | 3.7% | 23.7% | 9.9% | 61.8% |
| | Pre - Construction | Charlie | Buffered Bike Lane | NB | 6 | 16.7% | 83.3% | 0.0% | 0.0% | 0.0% |
| | | | Buffered Bike Lane | SB | 40 | 67.5% | 32.5% | 0.0% | 0.0% | 0.0% |
| | Construction | | Shared Lane (Signed) | NB | 292 | 1.4% | 2.7% | 12.3% | 2.7% | 80.8% |
| | | | Shared Lane (Signed) | SB | 570 | 1.1% | 3.9% | 26.3% | 14.2% | 54.6% |
| N Washington Ave, Minneapolis MN (44.988330, -93.277853) | | Bravo | Buffered Bike Lane | EB | 215 | 87.9% | 12.1% | 0.0% | 0.0% | 0.0% |
| | | | Buffered Bike Lane | WB | 283 | 79.2% | 20.1% | 0.4% | 0.0% | 0.4% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Charlie | Buffered Bike Lane | EB | 209 | 41.6% | 53.6% | 4.8% | 0.0% | 0.0% |
| | | Buffered Bike Lane | WB | 186 | 72.6% | 24.7% | 2.7% | 0.0% | 0.0% |
| | Delta | Buffered Bike Lane | EB | 130 | 47.7% | 45.4% | 6.9% | 0.0% | 0.0% |
| | | Buffered Bike Lane | WB | 290 | 61.4% | 34.1% | 4.5% | 0.0% | 0.0% |

**Table 4-1 Driver Behaviors in Vehicle-driver Interaction (Continue)**

| Study Location | | Camera | Type of Facility | Direction | Biker in facility with selected interactions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Interactions | No vehicle deviation (%) | Deviation in lane when overtaking (%) | Encroachment in adjacent lane when overtaking (%) | Full lane change into adjacent lane when overtaking (%) | Vehicle queued behind cyclist (%) |
| S Wayzata Blvd, Minneapolis MN (44.969905, -93.315383) | Phase 1 | Echo | No Facility | EB | 65 | 15.4% | 44.6% | 33.9% | 3.1% | 3.1% |
| | | | No Facility | WB | 32 | 0.0% | 46.9% | 43.8% | 3.1% | 6.3% |
| | Phase 2 | | Center Yellow | EB | 57 | 21.1% | 49.1% | 29.8% | 0.0% | 0.0% |
| | | | Center Yellow | WB | 40 | 7.5% | 62.5% | 25.0% | 0.0% | 5.0% |
| | Phase 3 | | Bike Lane | EB | 188 | 15.4% | 50.0% | 34.6% | 0.0% | 0.0% |
| | | | Bike Lane | WB | 93 | 6.5% | 50.5% | 39.8% | 3.2% | 0.0% |
| UMN, Pleasant St SE Minneapolis MN (44.975937, -93.236874) | | Alpha | Bike Lane | NB | 328 | 26.2% | 56.4% | 16.2% | 0.3% | 0.9% |
| | | | Bike Lane | SB | 1137 | 38.1% | 43.8% | 14.3% | 0.5% | 3.3% |
| | | Echo | No Facility | EB | 485 | 22.3% | 26.6% | 29.7% | 6.2% | 15.3% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| E Superior St Duluth MN (46.792402, -92.091129) | | No Facility | WB | 333 | 19.2% | 29.7% | 27.6% | 7.5% | 15.9% |
| | Foxtrot | No Facility | EB | 863 | 46.5% | 23.5% | 15.3% | 5.0% | 9.7% |
| | | No Facility | WB | 669 | 22.7% | 23.3% | 30.0% | 6.1% | 17.8% |
| Kenwood Ave Duluth MN (46.821591, -92.100451) | Foxtrot | Sharrows | NB Lane 1 (Shared) | 295 | 0.0% | 3.1% | 12.2% | 65.4% | 19.3% |
| | | Adjacent Through Lane | NB Lane 2 | 588 | 93.5% | 5.4% | 1.0% | 0.0% | 0.0% |
| | | Sharrows | SB Lane 1 (Shared) | 64 | 3.1% | 0.0% | 7.8% | 75.0% | 14.1% |
| | | Adjacent Through Lane | SB Lane 2 | 256 | 76.6% | 21.5% | 1.6% | 0.0% | 0.4% |

**Table 4-2 Changes in Cyclist Location on Veteran's Bridge**

| Facility Configuration | Observed Cyclists (Bin) | Cyclists (%) | Pedestrian Traffic (Bin Count) |
|---|---|---|---|
| Bike Lane v. Shared Lane | | | Total Count Observed; (Average Daily) |
| Shoulder (pre) EB | 358 | 37.0% | na[2] |
| Shared lane (post) EB | 133 | 11.8% | na[2] |
| Difference | -[1] | -25.2% | na[2] |
| Quasi-Bike lane (pre) WB | 380 | 26.7% | na[2] |
| Shared lane (post) WB | 169 | 11.9% | na[2] |
| Difference | -[1] | -14.7% | na[2] |
| Sidewalk v. Shared-use path | | | |
| Sidewalk (pre) EB | 560 | 58.0% | 1149 (34.24) |
| Shared –use path (post) EB | 955 | 84.7% | 1187 (42.39) |
| Difference | -[1] | +26.8% | +8.15 average daily |
| Sidewalk (pre) WB | 996 | 69.9% | 1579 (34.94) |
| Shared –use path (post) WB | 1206 | 85.2% | 1100 (39.23) |
| Difference | -[1] | +15.3% | +4.29 average daily |

[1]Not a direct comparison; [2]not applicable

## 4.2 MARSHALL AVENUE, ST. PAUL

Marshall Avenue in St. Paul is a minor arterial with an estimated AADT of 18,100 that becomes Lake Street in Minneapolis after a bridge crossing over the Mississippi River (Table 3-3). Marshall is heavily used by cyclists because it is one of the few bridges across the River. The site, which includes four travel lanes, is distinctive because it is the first location in the region which a shared lane (westbound (WB)) is designated by three signs through the corridor that states: "Bikes May Use Full Lane." No sharrows or other markings on the road to indicate a shared lane is present. The opposite (eastbound (EB)) side includes an in-street striped bike lane. The EB travel lane is 13-feet; the EB bike lane is 6 ft. The WB shared lane is 13 FT including 11 ft. asphalt and a two-foot gutter. Based on the assumption that the drivers and cyclists on opposite sides of the road are the same or similar, this site provides an opportunity to compare the relative effects of bike lanes and a shared lane indicated only with a signage. The configuration of the lanes is illustrated from different cameras in Photos C, D, and E.

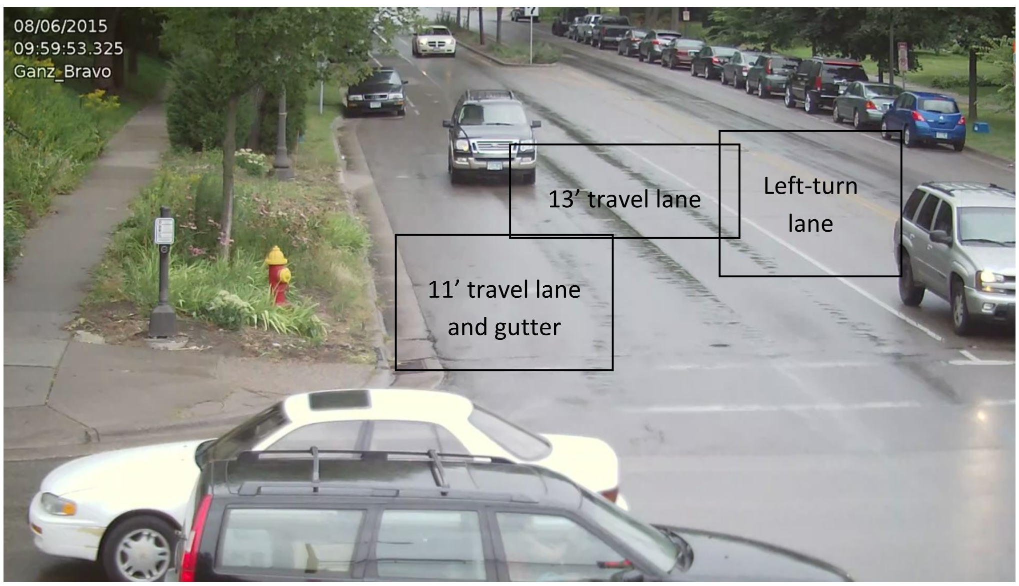


**Figure 4.3 Marshall Avenue Study Site (looking east; Bravo camera)**

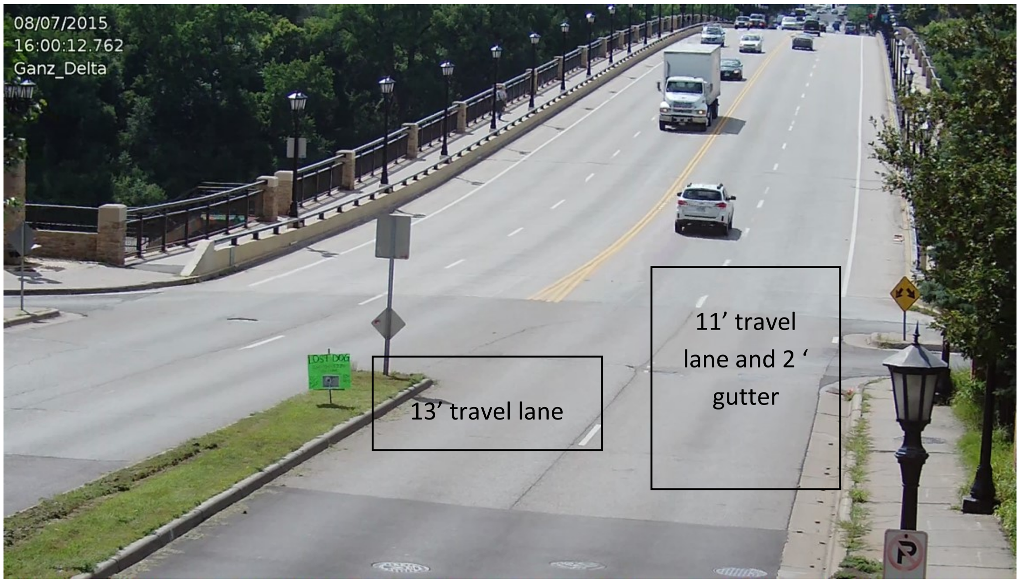


Figure 4.4 Marshall Avenue Study Site (looking west; Delta camera)


Figure 4.5 Marshall Avenue Study Site (looking west; Charlie camera)

### 4.2.1 Effects of the Striped Bike Lane and Signed Shared Lane

The results indicate drivers are more likely to encroach into the existing lane, pass or que when interacting with bicyclists on the WB signed shared lane than with bicyclists on the EB striped bicycle lane (Table 4-1). Of 1,366 interactions between vehicles and bicyclists in the striped lane, drivers did not deviate 95% of the time, and no deviations outside the travel lane or queueing occurred (Charlie camera).

Because of the site geometry, relatively few interactions on the WB signed shared lane were observed. Specifically, at the intersection immediately upstream from the observation area (seen in Photo C, Bravo Camera), Marshall consists of a right turn only lane and a travel lane. Downstream from the intersection, the right-hand lane becomes the signed shared lane. Most vehicles continue through the intersection and remain in the travel lane (left lane in Photo E); many of the vehicles in the shared lane enter Marshall at the intersection. Of the 67 interactions observed in the signed shared lane, 73% of the drivers queued behind the cyclist. Approximately 20% of the drivers deviated within the travel lane, encroached partially into the adjacent travel lane, or performed a complete passing maneuver. Only 7% of the drivers did not noticeably shift positions or queue.

### 4.2.2 Driver Avoidance of Shared Lane

The low number of interactions in the shared lane raises the possibility that drivers may be avoiding the shared lane. To address this issue, the team analyzed driver lane choice in two days of bin counts. This analysis showed that 61% of drivers chose to drive in the second (left-side) WB travel lane; 39% chose to drive in the signed, shared lane. It is difficult to determine whether this outcome is evidence that drivers may be avoiding the shared lane or represents an artifact of the configuration of the lanes at the intersections upstream and in the middle of the observation area.

## 4.3 COMO AVENUE, MINNEAPOLIS

Como Avenue is a major collector with an estimated AADT of 12,100 (Table 3-3). The location includes two travel lanes, bicycle facilities, and parking. The EB travel lane is a 13.5-foot shared traffic lane marked with sharrows (Photo D). The parking lane is 6.5 feet. The 11-foot WB lane included a 6-foot striped bicycle lane that had faded and was barely visible in some places (Photo E) and a parking lane. Like the Marshall Avenue site, this location provides the opportunity to compare different facilities on opposite sides of the same street, thus helping to control for variations introduced by different populations of drivers and cyclists.

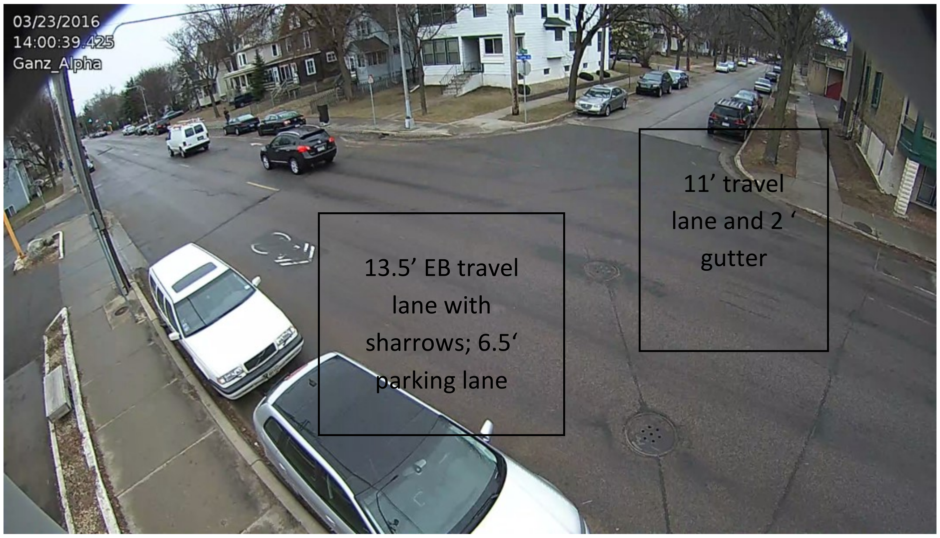


Figure 4.6 Como Avenue Study Site (looking west, Alpha camera)

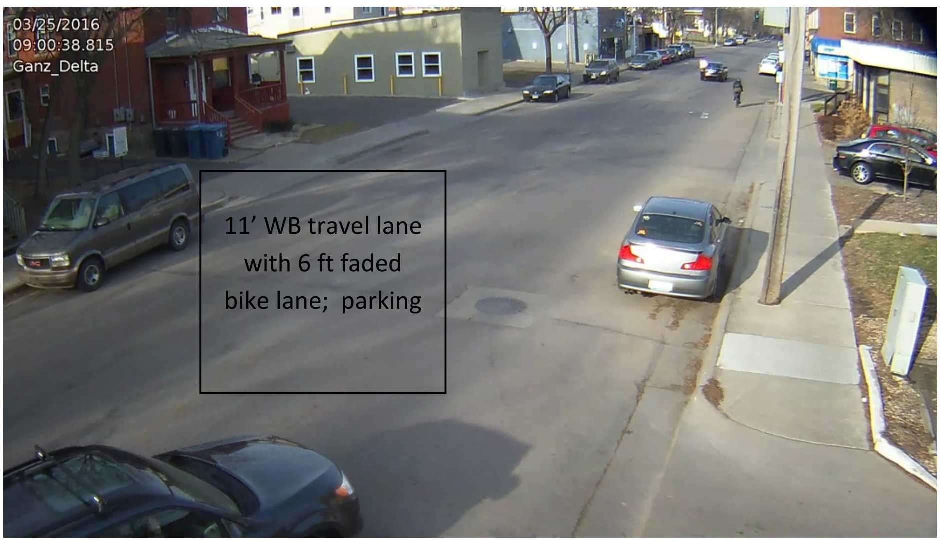


Figure 4.7 Como Avenue Study Site (looking east, Delta Camera)

### 4.3.1 Effects of the Striped Bike Lane and Sharrows

The Como Avenue results indicate drivers are more likely to alter behavior when interacting with bicyclists on a shared lane marked with sharrows than with bicyclists on a striped bicycle lane (Table 4-1). On the section of the roadway observable from the Alpha camera, nearly half (49%) of drivers did not deviate or queue when overtaking cyclists in the striped bicycle lane. Only 20% of drivers overtaking cyclists in the travel lane with sharrows did not deviate. Similarly, for the section of the roadway observable from the Delta camera, 76% of drivers did not deviate or queue when passing cyclists in the striped lane (even though the stripes were faded), but in the lane with sharrows, twenty-percent fewer

(56%) did not deviate or queue. Queuing occurred more frequently in lanes with sharrows than in lanes with striped bike lanes. The frequency of queuing during interactions was 2.8 times higher in the WB shared travel lane than in the EB travel lane adjacent to the striped bicycle lane. Observers noted that queuing often occurred even when a vehicle was not in the adjacent travel lane. Reasons for this are not known. Observers also note that striping and sharrows are faded, perhaps adding to uncertainty among drivers.

## 4.4 15TH AVENUE SE, MINNEAPOLIS

15th Avenue SE is a major collector near the University of Minnesota with an estimated AADT of 11,500 (Table 3-3). Many cyclists use this street to travel to the University because it is one of the few streets that crosses (via a viaduct) railroad tracks that block nearby parallel streets. 15th Avenue SE has been striped with a single white line dividing the vehicle traffic from the shoulder/bike lane since the early 2000's.

Construction occurred during the observation period on 15th Avenue south (Photo F). Results provide the opportunity to compare driver behaviors on:

- Striped bicycle lanes (pre-construction) and signed shared lanes (during construction), and
- Buffered bicycle lanes (pre-construction) and signed shared lanes (during construction).

### 4.4.1 Effects of Striped Bicycle Lanes and Signed Shared Lanes

The 15th Avenue SE results indicate drivers are more likely to alter behavior when interacting with bicyclists on a signed shared lane than with bicyclists on a striped bicycle lane (Table 4-1). In the NB and SB lanes, respectively, 86% and 76% of drivers deviated, passed, or queued when interacting with cyclists in the striped bicycle lane. In comparison, 97% and 99% of drivers deviated, passed, or queued when interacting with cyclists in the signed shared lane. The largest different occurred with respect to the frequency of queuing. Only 3% of NB and 2% of SB drivers queued when interacting with cyclists in the striped bike lane. In comparison, 68% of NB and 62% of drivers queued when interacting with cyclists in the signed shared lane.

### 4.4.2 Effects of Buffered Bicycle Lanes and Signed Shared Lanes

The 15th Avenue SE results also show drivers are more likely to alter behavior when interacting with bicyclists on a signed shared lane than with bicyclists on a buffered bicycle lane, (Table 4-1). Though relatively few observations (46) of interactions on the buffered bicycle lane are available, none of the drivers interacting with cyclists deviated into oncoming lanes, passed or queued. In comparison, more than 95% of the drivers who interacted with cyclists on the signed shared lane deviated into oncoming lanes, passed, or queued. The majority of drivers who interacted with cyclists on the signed shared lane queued: 81% and 55% on the NB and SB lanes, respectively.

In the NB and SB lanes, respectively, 86% and 76% of drivers deviated, passed, or queued when interacting with cyclists in the striped bicycle lane. In comparison, 97% and 99% of drivers deviated, passed, or queued when interacting with cyclists in the signed shared lane. The largest different occurred with respect to the frequency of queuing. Only 3% of NB and 2% of SB drivers queued when interacting with cyclists in the striped bike lane. In comparison, 68% of NB and 62% of drivers queued when interacting with cyclists in the signed shared lane.

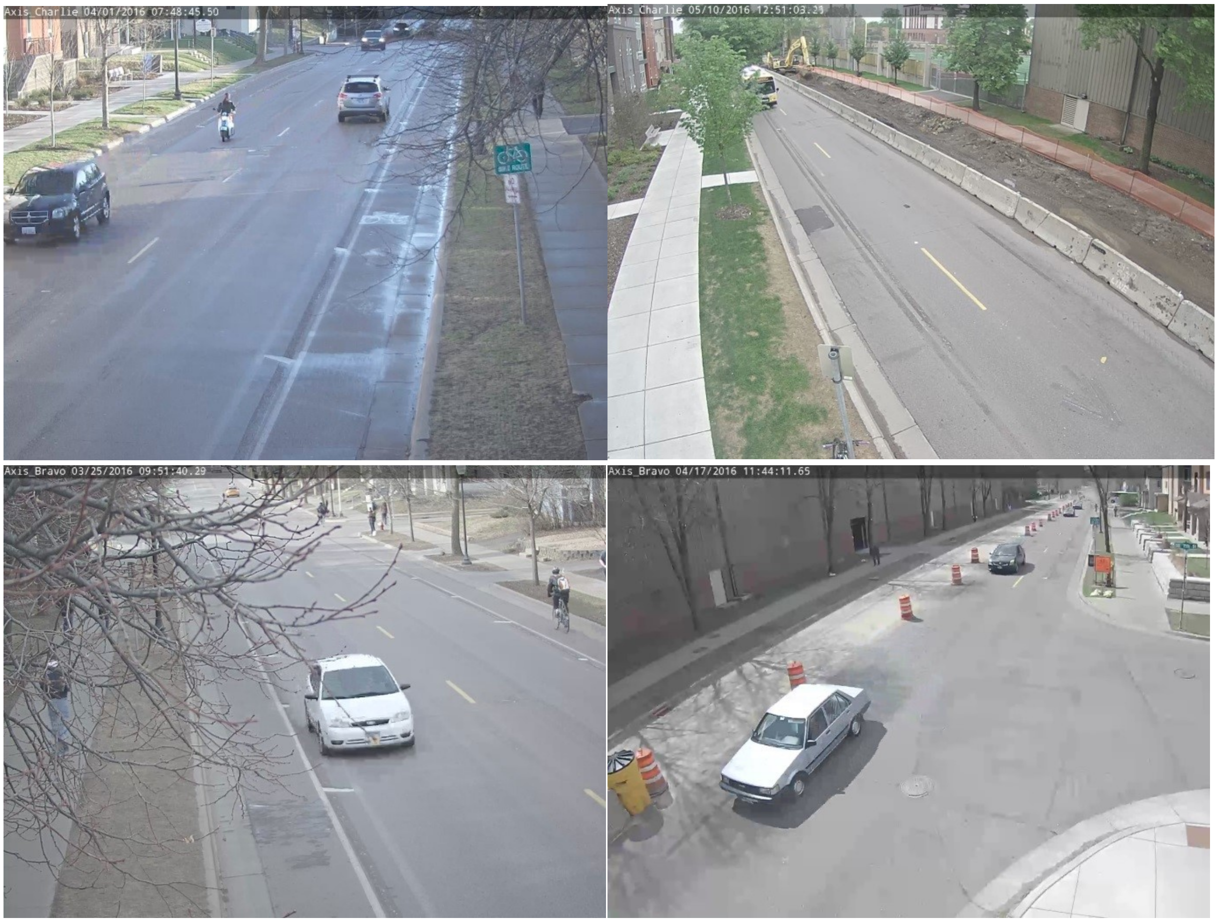


**Figure 4.8 15th Ave S Pre and Post (During Construction)**

## 4.5 N. WASHINGTON AVENUE, MINNEAPOLIS

N. Washington Ave. is a minor arterial with an estimated AADT of 14,800 (Table 3-3). Hennepin County in coordination with the city of Minneapolis has installed bicycle lanes in each direction that include two-foot buffers between the six feet bicycle lane and both the parking and travel lanes (Figure 4-9).

### 4.5.1 Effects of Buffered Bicycle Lanes

Results show that most drivers did not alter behavior when interacting with cyclists in the buffered bicycle lanes (Table 4-1). When observations for both lanes and three cameras are aggregated, 67% of drivers did not alter their trajectory when interacting or overtaking cyclists; an additional 30% deviated within the travel lane. Approximately 4% partially encroached on the oncoming travel lane.

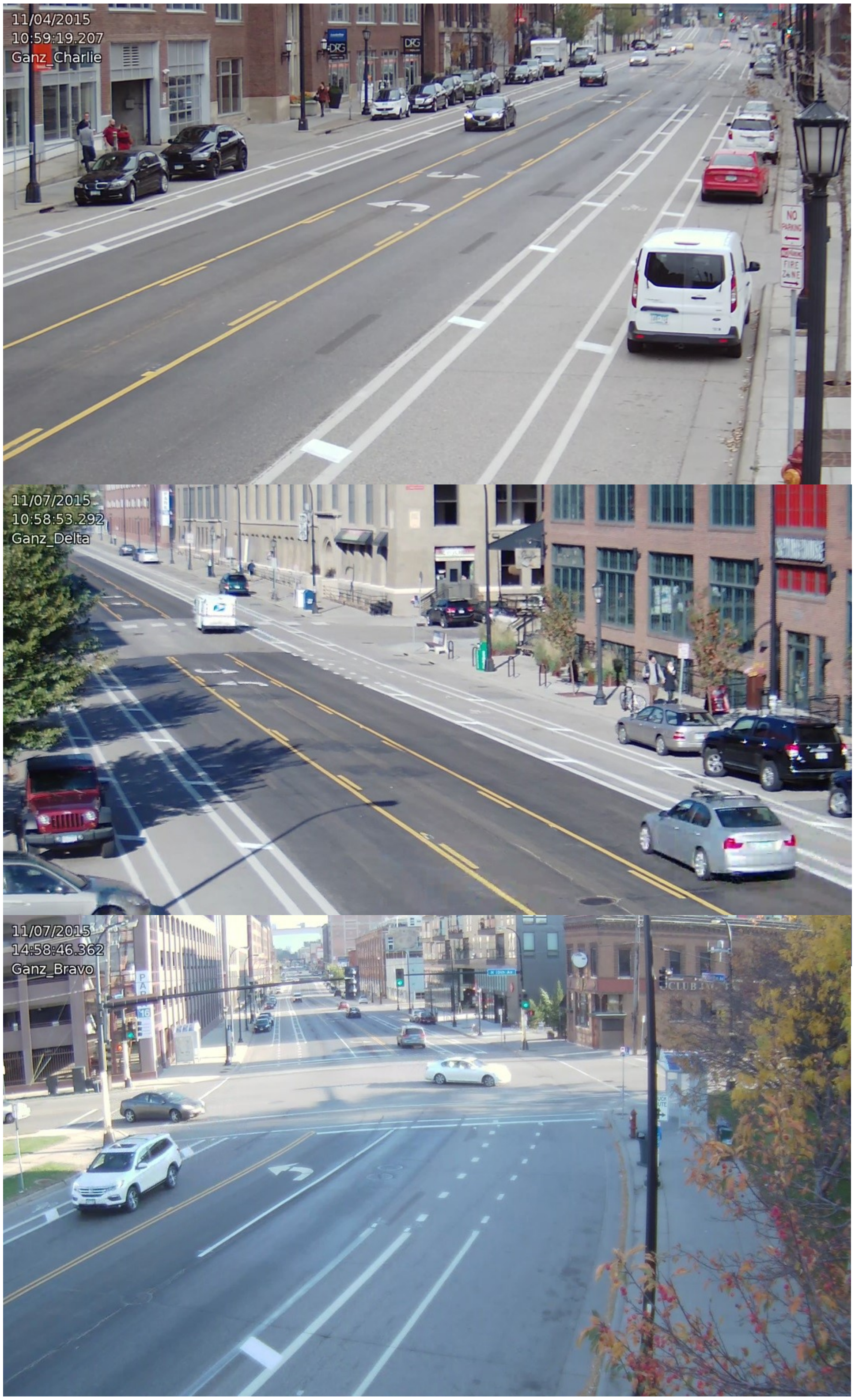


**Figure 4.9 Washington Ave**

## 4.6 WAYZATA BOULEVARD, MINNEAPOLIS

Wayzata Blvd. is an urban local road. No official AADT is available, but the average two-day count for traffic for the period from 5:00 a.m. to 18:00 p.m. was 5,980 (Table 3-3). This site included a 16 ft. travel lane with no lane markings and was reconstructed during the observation period. Following construction, the site included a 10 ft. travel lane and a 6 ft. striped bicycle lane (Photo H). Results provide the opportunity to compare interactions when the street include no bicycle facility or street markings, a center yellow line only, and a striped bicycle lane.

### 4.6.1 Effect of Striped Bicycle Lane

The results show comparatively small differences in driver behaviors across treatments (Table 4-1). The proportions of drivers who did not deviate when interacting with cyclists were 10% for with no bicycle facility or markings, 15% when the road was marked only with a yellow center line, and 12% when the striped bicycle lane was added. Across treatments, the most common behavior was to deviate within the lane. Full passing maneuvers were rare, occurring only a few times when no facilities were marked and when the striped bicycle lane was present. Similarly, queuing was observed only a few times in the absence of marked facilities and with the yellow; no queuing was observed when drivers interacted with bicyclists who were riding in the striped bicycle lane.


**Figure 4.10 Wayzata Blvd (looking east)**

## 4.7 PLEASANT STREET SE, UNIVERSITY OF MINNESOTA, MINNEAPOLIS

Pleasant St. SE is an urban local road on the University of Minnesota East Bank Campus. No official AADT is available, but the average two-day count for traffic for the period from 5:00 a.m. to 19:00 p.m. was 2,476 (Table 3-3). The roadway includes two bicycle lanes adjacent to each travel lane (Photo I). Observations for NB and SB lanes were combined for analysis because the bicycle lanes are comparable.

### 4.7.1 Effect of Striped Bicycle Lanes

Results indicate that the majority of drivers either do not deviate (35%) or deviate within lanes (47%) when interacting with bicyclists (Table 4-1). Approximately 15% of drivers encroached into the oncoming lane when interacting with cyclists. Few drivers made full passing maneuvers or queued behind cyclists.


**Figure 4.11 Pleasant Street SE, University of Minnesota East Bank Campus (looking north)**

## 4.8 E SUPERIOR STREET, DULUTH

E Superior St. is an urban local road without any bicycle facilities with an estimated AADT of 10800 (Table 3-3). A lane for parking is on the westbound side (Photo J). For purposes of analysis, observations from the two cameras at the site were combined, respectively, for EB and WB lanes.

### 4.8.1 Effect of Parking Facility

Approximately 38% of drivers on the EB lane did not deviate when interacting with cyclists; only 22% of drivers on the WB lane did not deviate (Table 4-1). Drivers in the WB lane were more likely to queue behind cyclists (17%) than were drivers in the EB lane (12%). In addition, drivers in the WB lane were more likely to encroach into the oncoming travel lane or to make complete passing movements.


Figure 4.12 Superior Street (looking west)

## 4.9 KENWOOD AVENUE, DULUTH

Kenwood Avenue is an urban local road with an estimated AADT of 11,100 (Table 3-3). The roadway includes two travel lanes in each direction; no parking is allowed on either side (Photo K). Sharrows have been painted in the right-hand travel lanes in each direction. Observations for the NB and SB lanes were combined for analysis because the facilities are comparable.

### 4.9.1 Effect of Sharrows

Almost all drivers (99.5%) who interacted with cyclists in the travel lanes with sharrows altered their trajectories and deviated, passed, or queued behind cyclists (Table 4-1). Sixty-five percent of the drives completed full passing maneuvers. Nearly 19% of drivers queued behind cyclists in the lanes marked with sharrows. The remaining drivers encroached into the adjacent travel lane or deviated but remained in the travel lane with the sharrows.


**Figure 4.13 Duluth Kenwood (looking south)**

## 4.10 SUMMARY OF DESCRIPTIVE RESULTS

The results show generally that drivers are less likely to alter their trajectories and deviate from their positions in the travel lanes or queue behind cyclists when facilities are clearly demarcated. Across the nine locations drivers on roadways with bicycle lanes (buffered or striped) were less likely to encroach into adjacent lanes, pass, or queue when interacting with cyclists than drivers on roadways with sharrows, signs designating shared lanes (with no sharrow markings), or no bicycle facilities. Queueing behind cyclist, the most significant impact on vehicular traffic flows, generally was highest on roads with shared facilities.

These results are seen clearly in Table 4-3, which ranks cases by the frequency of no deviation during interactions (i.e., no visible effects on traffic flows were observed). A case, which is defined as an outcome for a specific camera view for a facility, provides the most disaggregate perspective on the results and illustrates outcomes that might not be observable if data for similar types of facilities are combined for analysis. Across the nine locations, there were 45 cases. The 13 cases with the highest frequency of no observable effects all were locations with buffered or striped bicycle lanes. Among the 20 highest ranked sites, only three were lanes with sharrows or no facilities. Conversely, queuing occurred very infrequently or not at all on roadways with buffered or striped lanes. Queuing occurred more frequently on shared lanes, and, among types of shared lanes, generally more on signed lanes than on lanes with sharrows. However, some of the signed shared lanes were construction sites, which reduced space for maneuvering.

Table 4-4 provides a higher-level overview of results, focusing on the ranges of types of outcomes for the different types of facilities that were studied. The types of outcomes may be viewed as a continuum from no or minimal impact to greater impact on vehicular traffic flows:

- No deviation observed
- Stayed within lane (no deviation observed or deviation within lane)
- Moved out of lane (partial encroachment into adjacent lane or passing maneuver)
- Queued behind cyclist.

The types of facilities (i.e., the rows in Table 4-4) are ranked by the level of impact based on the range of outcomes observed for the cases for that particular facility type. Overall, this ranking shows that the greater the level or clarity of separation, the greater likelihood of no impacts on vehicular traffic, and the lower the likelihood of queueing behind cyclists. However, the results also show that variation within and across types of facilities and that the outcomes of interactions on specific types of facilities cannot be presumed to be the same.

Table 4-3 Types of Interactions by Facility Type, Ranked by Frequency of No Deviation (3 pages)

| Percent of Total Interactions | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0% | | | | | | 50% | | | | | | | 100% |

| Type of Facility (individual cases) | Direction | Driver Behaviors When Interacting With Cyclist | | | | | |
|---|---|---|---|---|---|---|---|
| | | Interactions | No vehicle deviation (%) | Deviation in lane when overtaking (%) | Encroachment in adjacent lane when overtaking (%) | Full lane change into adjacent lane when overtaking (%) | Vehicle queued behind cyclist (%) |
| 1. Adjacent Through Lane | WB Lane 2 | 256 | 97.3% | 2.0% | 0.4% | 0.4% | 0.0% |
| 2. Bike Lane | EB | 1366 | 95.0% | 4.9% | 0.1% | 0.0% | 0.0% |
| 3. Adjacent Through Lane | NB Lane 2 | 588 | 93.5% | 5.4% | 1.0% | 0.0% | 0.0% |
| 4. Buffered Bike Lane | EB | 215 | 87.9% | 12.1% | 0.0% | 0.0% | 0.0% |
| 5. Wide Shoulder | WB | 1032 | 84.3% | 13.2% | 2.5% | 0.0% | 0.0% |
| 6. Buffered Bike Lane | WB | 283 | 79.2% | 20.1% | 0.4% | 0.0% | 0.4% |
| 7. Bike Lane | EB | 620 | 77.1% | 21.9% | 0.8% | 0.0% | 0.2% |
| 8. Adjacent Through Lane | SB Lane 2 | 256 | 76.6% | 21.5% | 1.6% | 0.0% | 0.4% |
| 9. Faded Bike Lane | EB | 772 | 76.4% | 11.0% | 3.1% | 0.0% | 9.5% |
| 10. Buffered Bike Lane | WB | 186 | 72.6% | 24.7% | 2.7% | 0.0% | 0.0% |
| 11. Buffered Bike Lane | SB | 40 | 67.5% | 32.5% | 0.0% | 0.0% | 0.0% |
| 12. Buffered Bike Lane | WB | 290 | 61.4% | 34.1% | 4.5% | 0.0% | 0.0% |
| 13. Wide Shoulder | EB | 1324 | 58.6% | 29.4% | 8.6% | 1.3% | 2.1% |
| 14. Sharrows | WB | 1091 | 55.9% | 5.6% | 7.3% | 1.0% | 30.2% |

Table 4-3Types of Interactions by Facility Type, Ranked by Frequency of No Deviation (Continued)

| Type of Facility (individual cases) | Direction | Driver Behaviors When Interacting With Cyclist | | | | | |
|---|---|---|---|---|---|---|---|
| | | Interactions | No vehicle deviation (%) | Deviation in lane when overtaking (%) | Encroachment in adjacent lane when overtaking (%) | Full lane change into adjacent lane when overtaking (%) | Vehicle queued behind cyclist (%) |
| 15. Bike Lane | EB | 292 | 48.9% | 33.6% | 15.8% | 1.7% | 0.0% |
| 16. Buffered Bike Lane | EB | 130 | 47.7% | 45.4% | 6.9% | 0.0% | 0.0% |
| 17. No Facility | EB | 863 | 46.5% | 23.5% | 15.3% | 5.0% | 9.7% |
| 18. Buffered Bike Lane | EB | 209 | 41.6% | 53.6% | 4.8% | 0.0% | 0.0% |
| 19. Shared Turn Lane | WB Lane 2 (Through) | 70 | 40.0% | 1.4% | 1.4% | 0.0% | 57.1% |
| 20. Bike Lane | SB | 1137 | 38.1% | 43.8% | 14.3% | 0.5% | 3.3% |
| 21. Wide Shoulder | EB | 365 | 28.5% | 55.6% | 15.3% | 0.0% | 0.6% |
| 22. Bike Lane | NB | 328 | 26.2% | 56.4% | 16.2% | 0.3% | 0.9% |
| 23. Bike Lane | SB | 2495 | 23.9% | 72.1% | 1.6% | 0.0% | 2.3% |
| 24. No Facility | WB | 669 | 22.7% | 23.3% | 30.0% | 6.1% | 17.8% |
| 25. No Facility | EB | 485 | 22.3% | 26.6% | 29.7% | 6.2% | 15.3% |
| 26. Center Yellow | EB | 57 | 21.1% | 49.1% | 29.8% | 0.0% | 0.0% |
| 27. Sharrows | WB | 417 | 20.1% | 33.6% | 29.3% | 14.6% | 2.4% |
| 28. No Facility | WB | 333 | 19.2% | 29.7% | 27.6% | 7.5% | 15.9% |
| 29. Buffered Bike Lane | NB | 6 | 16.7% | 83.3% | 0.0% | 0.0% | 0.0% |
| 30. Bike Lane | EB | 188 | 15.4% | 50.0% | 34.6% | 0.0% | 0.0% |
| 31. No Facility | EB | 65 | 15.4% | 44.6% | 33.9% | 3.1% | 3.1% |

| Type of Facility (individual cases) | Direction | Driver Behaviors When Interacting With Cyclist | | | | | |
|---|---|---|---|---|---|---|---|
| | | Interactions | No vehicle deviation (%) | Deviation in lane when overtaking (%) | Encroachment in adjacent lane when overtaking (%) | Full lane change into adjacent lane when overtaking (%) | Vehicle queued behind cyclist (%) |
| 32. Bike Lane | NB | 1282 | 14.4% | 79.4% | 3.5% | 0.0% | 2.7% |
| 33. Center Yellow | WB | 40 | 7.5% | 62.5% | 25.0% | 0.0% | 5.0% |
| 34. Shared Lane (Signed) | WB Lane 1 (shared) | 67 | 7.5% | 1.5% | 11.9% | 6.00% | 73.1% |
| 35. Wide Shoulder | WB | 305 | 7.2% | 65.9% | 20.3% | 5.6% | 1.0% |
| 36. Bike Lane | WB | 93 | 6.5% | 50.5% | 39.8% | 3.2% | 0.0% |
| 37. Narrow Shoulder | EB | 238 | 3.4% | 23.1% | 57.1% | 10.9% | 5.5% |
| 38. Sharrows | SB Lane 1 (Shared) | 64 | 3.1% | 0.0% | 7.8% | 75.0% | 14.1% |
| 39. Shared Lane (Signed) | NB | 204 | 2.9% | 10.3% | 16.2% | 2.9% | 67.7% |
| 40. Narrow Shoulder | WB | 139 | 2.9% | 33.8% | 41.7% | 18.0% | 3.6% |

**Table 4-3Types of Interactions by Facility Type, Ranked by Frequency of No Deviation (Continued)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 41. Shared Lane (Signed) | NB | 292 | 1.4% | 2.7% | 12.3% | 2.7% | 80.8% |
| 42. Shared Lane (Signed) | SB | 570 | 1.1% | 3.9% | 26.3% | 14.2% | 54.6% |
| 43. Shared Lane (Signed) | SB | 685 | 1.0% | 3.7% | 23.7% | 9.9% | 61.8% |
| 44. No Facility | WB | 32 | 0.0% | 46.9% | 43.8% | 3.1% | 6.3% |
| 45. Sharrows | NB Lane 1 (Shared) | 295 | 0.0% | 3.1% | 12.2% | 65.4% | 19.3% |

Table 4-4 Frequencies of Types of Interactions by Facility Types

| Type of Facility (cases) | No Deviation | | No Deviation or Deviated in Lane | | Encroached in Adjacent Lane or Passed | | Queued Behind Cyclist | |
|---|---|---|---|---|---|---|---|---|
| | Low | High | Low | High | Low | High | Low | High |
| Adjacent Through Lane (3) | 76.6% | 97.3% | 98.0% | 99.2% | 0.8% | 1.6% | 0.0% | 0.4% |
| Buffered Bike Lane (9) | 16.7% | 87.9% | 93.1% | 100% | 0.0% | 6.9% | 0.0% | 0.4% |
| Striped Bike Lane (8) | 6.5% | 95.0% | 57.0% | 99.9% | 0.1% | 43.0% | 0.0% | 3.3% |
| Faded Bike Lane (1) | 76.4% | 76.4% | 87.4% | 87.4% | 3.1% | 3.1% | 9.5% | 9.5% |
| Wide Shoulder (4) | 7.2% | 84.3% | 73.1% | 97.5% | 2.5% | 25.9% | 0.0% | 2.1% |
| Narrow Shoulder (2) | 2.9% | 3.4% | 26.5% | 36.7% | 59.7% | 68.1% | 3.6% | 5.5% |
| Sharrows (4) | 0.0% | 55.9% | 3.1% | 61.5% | 8.3% | 82.8% | 2.4% | 30.2% |
| Shared Lane (signed) (5) | 1.0% | 7.5% | 4.1% | 13.2% | 15.1% | 40.5% | 54.6% | 80.8% |
| Shared Turn Lane (1) | 40.0% | 40.0% | 41.4% | 41.4% | 1.4% | 1.4% | 57.1% | 57.1% |
| Shared - Center Yellow (2) | 7.5% | 21.1% | 70.0% | 70.2% | 25.0% | 29.8% | 0.0% | 5.0% |
| No Facility (6) | 0.0% | 46.5% | 46.0% | 70.0% | 20.3% | 46.9% | 3.1% | 17.8% |

## 4.11 MODELING BICYCLE-VEHICLE INTERACTIONS

The research team estimated regression models to assess the significance of factors associated with specific driver behaviors that can affect traffic flow. Definitions of variables used in the regression models are summarized in Table 4-5. Regression results for two models are presented in Tables 4-6 and 4-7. The principal difference between these two models concerns the number of cases included in each regression. Four of the 45 cases (Table 4-3) were excluded from both models because the cases were atypical and not generally representative of the effects of bicycle facilities on traffic in adjacent lanes. Specifically, the four excluded cases were cases of left-most lanes on Marshall Avenue in St. Paul and Kenwood in Duluth. The results for these cases reported in the descriptive results are valid, but because these do not match directly the configurations of all other cases, the team believes they are not representative of the direct effects of interactions between vehicles and cyclists in adjacent lanes. The removal of these cases resulted in a sample of 41 cases (Table 4-6). In the second regression, the results from Wayzata Phase 3 (post-construction) were excluded because, among the cases involving striped bicycle lanes, Wayzata Phase III was an outlier. The regression in Table 4-7 therefore includes 39 cases.

The dependent variable in both models is driver behavior when interacting with a cyclist, specifically, the percentage of drivers who, when interacting with a cyclists, did not deviate or deviated but remained entirely within their travel lane (No_OutOfLane_Deviation).

The independent variables include the type of bicycle facility, the functional class of the roadway, width of travel lane, and vehicular AADT (Table 4-5). All bicycle facility variables, which are considered an attribute of a roadway, are dichotomous variables, taking on values of 1 if the roadway includes that particular type of facility (or facility combination), and a value of 0 if otherwise. Because of the small sample size, where descriptive results indicated categories of facilities functioned similarly, categories were combined. For example, striped lanes, faded striped lanes, and wide shoulders were combined into a single category for the regression. The "no facility" cases are omitted, and the effects of facility type should be interpreted relative to no facility. Roadways are classified by functional class and also are represented by dichotomous variables. The functional class "urban local roads" is omitted from the regression; all results, therefore must be interpreted as effects relative to urban local roads.

Table 4-5 also includes the expected effects (positive or negative) of bicycle facilities on the dependent variable. For example, based on both the literature review and the descriptive results, it is expected that the presence of buffered or striped bike lanes will increase the percentage of drivers who do not alter their trajectories or do so but remain in their lanes (relative to streets with no facilities). Sharrows are designed to alert drivers of the presence of cyclists and convey the message that cyclists have rights to occupy a travel lane. The research team hypothesized that sharrows (or road with signs to indicated shared use) would not be as effective as striped lanes, but did not have a priori hypotheses about their effectiveness relative to no facilities. All else equal, it was expected that wider travel lanes would increase the percentage of drivers remaining in their lane when interacting with cyclists. The team had no a priori expectations for the effects of functional class or vehicular AADT.

The regression results generally confirmed the patterns identified in the descriptive results. Relative to roadways with no bicycle facilities, the percentage of drivers who remained in their lanes when interacting with cyclists was positively and significantly correlated with the presence of both buffered and striped bicycle lanes (Tables 4-6, 4-7). The effects of roadways with shared facilities relative to roadways with no facilities were ambiguous and inconclusive. In both models, neither the effects of sharrows nor the effects narrow shoulders or signed facilities were significantly different from roadways with no facilities. In fact, the signs on the coefficients were negative, indicating that, relative to roadways with no facilities, drivers on roadways with sharrows or signed facilities were more like to encroach into adjacent lanes, pass, or queue. Though neither outcome was statistically significant, the relative influence of sharrows was substantially smaller than the influence of signed or narrow shoulder facilities. The magnitude of these relative effects was as expected; that is, it was expected that sharrows painted on roadways would produce an effect greater than that of signed, shared lanes.

Table 4-5 Variables Included in Regression Models

| Variables | Description | Expected Effect on Staying in Lane During Interaction (relative to no facilities) |
|---|---|---|
| *Dependent Variable* | | |
| G_NO_OutOfLane_Deviation | % of drivers who did not deviate or deviated within their travel lane when interacting with (i.e., passing) a cyclist | NA |
| *Independent Variables* | | |
| Y_Buffered_BL | Facility type: buffered bicycle lane = 1, 0 otherwise | + |
| W_Striped+Faded+Wide | Facility type: striped bicycle lane, faded bicycle lane, and wide shoulder = 1; 0 otherwise | + |
| Y_Sharrows | Facility type: sharrows = 1; 0 otherwise | ? |
| W_Signed+Narrow+Center_line | Facility type: signed shared lane (no sharrows) or unmarked narrow lane and center line only = 1; 0 otherwise | ? |
| R_Major_Col | Roadway functional class: major collector = 1; 0 otherwise | ? |
| R_Minor_Art | Roadway functional class: minor arterial = 1; 0 otherwise | ? |
| R_Principal_Art | Roadway functional class: major arterial = 1; 0 otherwise | ? |
| R_Travel_Lane | Width of vehicular travel lane in feet | + |
| R_AADT_2013 | Estimated annual average daily vehicular traffic (AADT; source = MnDOT) | ? |

Table 4-6 A Model of Driver Behavior when Interacting with Bicyclists (n=41)

| Variable | Estimate | Standard Error | t-statistic* | p-value** |
|---|---|---|---|---|
| **Constant** | **-67.425** | **32.154** | **-2.097** | **0.0443** |
| **Buffered_BL** | **75.9799** | **16.106** | **4.718** | **0.0001** |
| **Striped+Faded+Wide** | **53.4061** | **12.094** | **4.416** | **0.0001** |
| Sharrows | -2.6723 | 14.994 | -0.178 | 0.8597 |
| Signed+Narrow | -20.344 | 14.356 | -1.417 | 0.1664 |
| Major_Col | -5.2326 | 11.96 | -0.438 | 0.6648 |
| Minor_Art | -28.57 | 16.881 | -1.692 | 0.1006 |
| Principal_Art | -31.713 | 22.081 | -1.436 | 0.161 |
| **Travel_Lane** | **7.12144** | **1.9692** | **3.616** | **0.001** |
| **AADT_2013** | **0.0026** | **0.0011** | **2.296** | **0.0286** |
| Dependent variable: % of drivers who did not deviate or deviated within their travel lane | | | | |
| Adj. $R^2 = 0.91$ | | | | |
| ***Excludes Marshall Avenue and Kenwood Avenue cases with adjacent through lanes.<br>**Bold = Statistically significant at 5% level** | | | | |

Table 4-7 A Model of Driver Behavior in When Interacting with Bicyclists (n=39)

| Variable | Estimate | Standard Error | t-statistic* | p-value** |
|---|---|---|---|---|
| **Constant** | **-67.6519** | **30.3341** | **-2.23** | **0.0336** |
| **Buffered_BL** | **92.4049** | **16.7275** | **5.524** | **0.0000** |
| **Striped+Faded+Wide** | **68.2921** | **13.0533** | **5.232** | **0.0000** |
| Sharrows | 15.1393 | 16.0517 | 0.943 | 0.3534 |
| Signed+Narrow | -5.44159 | 14.9575 | -0.364 | 0.7186 |
| **Major_Col** | **-24.9183** | **14.0576** | **-1.773** | **0.0868** |
| **Minor_Art** | **-52.1516** | **18.829** | **-2.77** | **0.0097** |
| **Principal_Art** | **-59.2515** | **23.9072** | **-2.478** | **0.0193** |
| **Travel_Lane** | **6.6424** | **1.86885** | **3.554** | **0.0013** |
| **AADT_2013** | **0.00345** | **0.00113** | **3.062** | **0.0047** |
| Dependent variable: % of drivers who did not deviate or deviated within their travel lane | | | | |
| Adj. $R^2 = 0.93$ | | | | |
| ***Excludes Marshall Avenue and Kenwood Avenue cases and Wayzata Ave Phase 3 (outlier).<br>**Bold = Statistically significant at 5% level** | | | | |

As expected, the percentage of drivers who remained in their lanes was positively and significantly correlated with the width of the travel lane (Tables 4-6, 4-7). The effects of being on a higher class functional road (relative to an urban local road) varied in the two models. The effects were negative but not statistically significant in the model that eliminated only the left-side through lanes, but negatively and significantly correlated with the percentage of drivers who remain in their lanes in the model that eliminated the Wayzata outlier (Table 4.7). The reasons for these outcomes are unclear.

Overall, the Adjusted $R^2$ values for both models were quite high (i.e., > 90%), indicating the models account for most of the variation observed in driver behavior. That is, driver interactions with bicyclists are systematically associated with type of bicycle facility, road functional class, travel lane width, and traffic volumes.

Limitations of these models include the relatively small sample size and the potential for multicollinearity among the independent variables. The number of cases in the sample was limited by the resources available for the study. The potential for multicollinearity exists because particular types of bicycle facilities may be more likely to be associated with roads of a particular functional class. The potential for multicollinearity means that the true association between the dependent variable and any particular independent variables may not be represented accurately by the coefficients on the variables in the equations. This means, in turn, that common interpretations of regression equations may not hold. For example, a common interpretation of the effect of the width of the vehicular travel lane on driver behavior would be that, all other factors equal (and holding values of other independent variables at their mean values), an increase of one foot in the width of a travel lane increases the percentage of drivers who remain in their lane by about 7% (Tables 4-6, 4-7). However, if travel lane width is correlated with a particular road type, this interpretation of the magnitude of relationship may not be accurate. This limitation, however, does not affect the overall interpretation that the set of variables included in the model explain most of the observed variation in driver behavior.

In sum, these results show drivers are more likely to remain in their lanes and not encroach into adjacent lanes, pass, or queue when interacting with cyclists on roads with buffered or striped bicycle lanes than on roads with no facilities or shared travel lanes. These results also indicate there are no statistically significant differences between shared facility designs and roads with no facilities, at least in terms of frequency of drivers remaining in their travel lanes. Excluding the potential confounding effects of multi-collinearity in the models, the demarcation of lanes with a solid or double lines (buffer) increases the probability that drivers will not deviate from their lanes by 68% to 92%. Although not statistically significant, it appears drivers in shared lanes may be more likely to leave those lanes than drivers on roads with no facilities. This outcome does not assess the benefits that may occur because drivers on roads with sharrows may be more aware of the presence of cyclists.

An important limitation of this study is that none of the locations that were evaluated reached saturated flow conditions. However, to the extent flow breakdowns are associated with lane changes when roads are near capacity, these results suggest that bicycle lanes (i.e.,  the solid, striped lane(s)) have close to three times the chance of preventing a flow breakdown and the generation of queues.

# CHAPTER 5: IMPLICATIONS FOR DESIGN GUIDELINES AND CONCLUSIONS

The principal objectives of this study were to increase study and document the effects of bicycle facilities on driver behavior and traffic flows and to summarize the implications for design. Field investigations were completed at nine locations and included 45 cases that represent a range of types of bicycle facilities on different functional classes of roads. The results show that drivers are more likely to remain in their travel lanes, and are less likely to encroach into adjacent lanes, pass, or queue behind cyclists, when interacting with cyclists on roads with buffered or striped bicycle lanes than on roads with sharrows, shared-use lanes marked only with signs, or no facilities. These results therefore add to the body of evidence in the literature that the addition of buffered and striped bicycle lanes to a roadway increases the predictability of driver behavior, increases the likelihood that drivers will remain in their travel lanes, and reduces the risk that may be associated with drivers encroaching into or shifting travel lanes.

To illustrate how these findings augment existing design guidelines, we extracted existing design guidelines for buffered bike lanes, striped bike lanes, sharrows, wide shoulders, and signed lanes from guidance prepared by NACTO (2014) and AASHTO (2012). Relevant sections of these documents, including the relative advantages and disadvantages of buffered lanes, striped lanes, and sharrows, are reproduced in Tables 5-1 through 5-3. Existing MnDOT (2007) guidelines are not included in these tables because they are being updated and including them could result in presentation of outdated information. We do, however, reference MnDOT (2007) design guidelines where relevant. We also cite provisions from the FHWA's Manual of Uniform Traffic Control Devices (MUTCD 2009) where relevant.

## 5.1 CONSIDERATIONS IN THE DESIGN OF BUFFERED BICYCLE LANES

Buffered bicycle lanes create separation and sometimes include physical barriers between bicycles and vehicles (Table 5-1). Among other benefits, buffered bicycle lanes provide room for cyclists to maneuver and increase perceptions of safety, which in turn may increase participation in bicycling. Buffered bicycle lanes can be applied in most places where standard bicycle lanes can be used, depending on the right-of-way width and the availability of space, but special considerations are warranted at transit stops to minimize conflicts between cyclists and pedestrians. Neither the NACTO (2014) nor AASHTO (2012) guidelines specifically mention studies of interactions between bicyclists and vehicles on buffered bicycle lanes, but it is implicit within them that the separation between vehicular travel lanes and bicycle lanes minimizes interactions between cyclists and vehicles.

Our results confirm that the separation associated with buffered bicycle lanes minimizes interactions along roadways that potentially pose risk and impacts on traffic. Between 93% and 100% of drivers did not deviate from their lanes when overtaking cyclists in adjacent buffered bicycle lanes (Table 4-4). Queuing behind cyclists in the adjacent buffered bicycle lane occurred in less than one percent of cases. The regression models confirm that, all else equal, drivers in lanes adjacent to buffered bicycle lanes are more likely to remain in lanes when compared to roads with no facilities, thus minimizing potential traffic impacts associated with bicycle-vehicle interactions.

These results are not surprising, but they do provide additional perspective on established guidelines with respect to driver behaviors. Specifically, an advantage of separated bicycle lanes is that impacts on driver behaviors and vehicular traffic flows along roadways are essentially eliminated. Integration of separated bicycle lanes at intersections, however, poses challenges that were not investigated in this study.

**Table 5-1 Existing Design Guidelines for Buffered Bike Lane**

| **Advantages and Disadvantages** | |
|---|---|
| **NACTO Urban Bikeway Design Guide, Second Edition (2014)** *(p. 10)* | **AASHTO Guide to Bicycle Facilities, 4th Edition** (*ch.4 p.18)* |
| • *Provides greater shy distance between motor vehicles and bicyclists.*<br>• *Provides space for bicyclists to pass another bicyclist without encroaching into the adjacent motor vehicle travel lane.*<br>• *Encourages bicyclists to ride outside of the door zone when buffer is between parked cars and bike lane.*<br>• *Provides a greater space for bicycling without making the bike lane appear so wide that it might be mistaken for a travel lane or a parking lane.*<br>• *Appeals to a wider cross-section of bicycle users.*<br>• *Encourages bicycling by contributing to the perception of safety among users of the bicycle network.* | • *Striped buffers may be used to provide increased separation between a bike lane and another adjacent lane that may present conflicts.*<br>• *A buffer between the bike lane and the adjacent lanes places bicyclists further from the normal sight lines of motorists, who are primarily looking for vehicles in the lanes intended for motor-vehicle travel, and buffers between the bike lane and an adjacent travel lane reduce the natural "sweeping" effect of passing motor vehicles, potentially requiring more frequent maintenance.* |

*Text in italics directly from NACTO Urban Bikeway Design Guidelines and AASHTO Guide to Bicycle Facilities

**Table 5-2 Existing Design Guidelines for Striped Bike Lanes**

| **Advantages and Disadvantages** | |
|---|---|
| **NACTO Urban Bikeway Design Guide, Second Edition (2014)** *(p.4)* | **AASHTO Guide to Bicycle Facilities, 4th Edition** *(ch.4 p.11)* |
| • *Increases bicyclist comfort and confidence on busy streets.*<br>• *Creates separation between bicyclists and automobiles.*<br>• *Increases predictability of bicyclist and motorist positioning and interaction.*<br>• *Increases total capacities of streets carrying mixed bicycle and motor vehicle traffic.*<br>• *Visually reminds motorists of bicyclists' right to the street.* | • *Enable bicyclists to ride at their preferred speed, even when adjacent traffic speeds up or slows down.*<br>• *Encourage bicyclists to ride on the roadway in a position where they are more likely to be seen by motorists entering or exiting the roadway than they would be if riding on sidewalks.* |

*Text in italics directly from NACTO Urban Bikeway Design Guidelines and AASHTO Guide to Bicycle Facilities

**Table 5-3 Existing Design Guidelines for Sharrows**

| **Advantages and Disadvantage** | |
|---|---|
| **NACTO Urban Bikeway Design Guide, Second Edition (2014)** *(p. 134)* | **AASHTO Guide to Bicycle Facilities, 4th Edition** *(ch.4 p.4)* |
| • *Encourages bicyclists to position themselves safely in lanes too narrow for a motor vehicle and a bicycle to comfortably travel side by side within the same traffic lane.*<br>• *Alerts motor vehicle drivers to the potential presence of bicyclists.*<br>• *Alerts road users of the lateral position bicyclists are expected to occupy within the travel lane.*<br>• *Indicates a proper path for bicyclists through difficult or potentially hazardous situations, such as railroad tracks.*<br>• *Advertises the presence of bikeway routes to all users.*<br>• *Provides a wayfinding element along bike routes.*<br>• *Demonstrated to increase the distance between bicyclists and parked cars, keeping bicyclists out of the "door zone."*<br>• *Encourages safe passing by motorists.*<br>• *Requires no additional street space. Reduces the incidence of sidewalk riding.*<br>• *Reduces the incidence of wrong way bicycling.* | • Used in situations where a higher level of guidance is desirable.<br>• *Useful in locations with there is insufficient width to provide bike lanes.*<br>• Encourages *safer passing practices.*<br>• May be used to reduce wrong-way bicycling.<br>• *In a shared lane with adjacent on-street parallel parking,* assists *bicyclist with lateral positioning that reduces chance of bicyclist impacting the open door of a parked vehicle.*<br>• Helps with positioning on wide outside lane.<br>• *Can fill gap between two sections of roadway that have bike lanes.* |

*Text in italics directly from NACTO Urban Bikeway Design Guidelines and AASHTO Guide to Bicycle Facilities

## 5.2 CONSIDERATIONS IN THE DESIGN OF STRIPED BICYCLE LANES

Striped bicycle lanes create separation between cyclists and vehicles, increase predictability of bicyclist and motorist position and interactions, remind motorists of bicyclists' rights to use streets, and increase capacity of streets for carrying both vehicular and bicycle traffic (Table 5-2). Among other benefits, they enable cyclists to adjust and ride at preferred speeds. Neither the NACTO (2014) nor AASHTO (2012) guidelines specify that striped bicycle lanes are particularly useful on arterials and collectors with AADTs greater than 3,000 and posted speed limits greater than 25 m.p.h. The guidelines recommend that bicycle lanes also be provided on both sides of two-way streets. MnDOT (2007) notes that striped lanes accommodate bicycles better than shared or wide outside lanes and have a "strong channelizing effect on motor vehicles and bicycles."

Our results confirm and provide additional evidence in support of the NACTO (2014), AASHTO (2012), and MnDOT (2007) guidelines regarding the benefits of striped bicycle lanes. However, drivers on roadways with striped bicycle lanes were somewhat more likely to deviate from their lanes when interacting with cyclists than drivers on roads with buffered bicycle lanes. However, the majority of drivers, between 57% and 99%, remained in their lanes when interacting with cyclists (Table 4-4). At one location, 43% of drivers encroached into the adjacent lane or completed a full passing maneuver when interacting cyclists. Queuing behind cyclists in striped lanes rarely occurred. At one location where the striped lane had faded and was barely visible, approximately 10% of drivers interacting with cyclists queued behind them.

The regression models confirm that, all else equal, drivers are significantly more likely to remain in their lanes when interacting with cyclists in bicycle lanes than when on roads with no bicycle facilities. In addition, the models show that compared to sharrows and signed, shared roadways, drivers are less likely to alter their trajectories or encroach into adjacent lanes.

An implication of these analyses is that striped lanes can be used on roadways that approach saturation conditions because the minimal interaction reduces the probability that the presence of bicycles or interactions will cause flow breakdowns. These findings also have implications for procedures in the Highway Capacity Manual (HCM) for determining Level of Service (LOS). When LOS is calculated, Passenger Car Equivalents (PCEs) may be estimated and bicycle volumes may be added to vehicle volumes. These findings indicate that adjustment factors for PCEs on roadways with striped lanes may be less than one (or in some cases zero) and that additional study of the need to add bicycle and vehicular volumes when determining LOS is warranted.

## 5.3 CONSIDERATIONS IN THE DESIGN OF SHARROWS

Sharrows alert drivers to the potential presence of bicyclists but do not provide separation between vehicles and bicycles (Table 5-3). Among other benefits, sharrows are believed to help with positioning of cyclists relative to parked cars and to encourage safe passing by motorists. The NACTO (2014) guidelines state that sharrows should not be considered a substitute for buffered or striped bicycle lanes. Both the NACTO (2014) and AASHTO (2012) guidelines note that sharrows potentially may be applied on arterials or collectors and on roadways where space does not allow installation of bicycle lanes. These guidelines note sharrows may be used on bicycle boulevards and in other contexts to enhance wayfinding. The FHWA MUTCD (2009) provides technical guidance for placement of sharrows, including location of sharrow markings on roadways and in relation to interactions.

Our results regarding the effects of sharrows are mixed. Although the descriptive results indicate sharrows increase predictability of drivers relative to roads with no facilities, the regression models indicate there are no significant differences between roadways with sharrows and local roads with no facilities in terms of the frequency that drivers remain in their travel lanes. On roadways with sharrows, the percentage of drivers who remained in their lanes when interacting with cyclists ranged from 3.1% to 62% (Table 4-4). Between 8% and 83% of drivers interacting with cyclists either encroached into adjacent lanes or completed full passing maneuvers. In one case, 30% of drivers queued behind cyclists. The regression models, as noted, show no significant effects associated with sharrows. Other benefits of sharrows (e.g., wayfinding) were not assessed. The finding that traffic impacts associated with sharrows may not be significantly different than streets with no facilities may be useful for clarifying road and bicycle design guidelines that describe the advantages and disadvantages of sharrows.

An implication of these analyses is that shared lanes with sharrows may be ill-advised on roadways that approach saturation conditions because the likely outcomes of interactions are increases in the probability of flow breakdowns. With respect to the methods in the HCM for determining LOS, bicycle volumes should be added to the vehicle volumes for facilities with sharrows. In the estimation of PCEs, the adjustment factor may be 1 or greater.

## 5.4 CONSIDERATIONS IN THE DESIGN OF WIDE SHOULDERS

Unmarked, wide shoulders along urban roadways may function similarly to bicycle lanes, but because they typically have not been designed as bicycle facilities, there is less guidance concerning implications of their use. The NACTO (2014) guidelines, for example, include do not address wide shoulders as a separate category of facility. AASHTO (2012) guidelines state that wide shoulders (≥ five feet) are best used on rural highways with higher speeds (e.g., 40-55 m.p.h.) and that rumble strips should be avoided. MnDOT (2007) guidelines are similar to the AASHTO guidelines, stating that shoulders should be between four and ten feet wide and wider on roadways with higher volumes.

Our results indicate that, depending on their width, wide shoulders may function similarly to striped bicycle lanes. When interacting with cyclists on streets with wide (unmarked) shoulders, between 73% and 98% of drivers remained within their travel lanes. The highest frequency of vehicular queuing behind cyclists on wide shoulders was two percent. On the two roadways with narrow shoulders (and no bicycle facilities), the observed outcomes were comparable to roadways with sharrows, with a majority of motorists encroaching into adjacent lanes or passing when interacting with cyclists. The regression results, in which facilities with wide shoulders were grouped with striped lanes, indicate that motorists are more likely to remain in their lanes when interacting with cyclists on roads with wide shoulders (relative to drivers on roadways with no facilities). With respect to the procedures in the HCM for estimating LOS, the implications may be comparable to those described for striped lanes.

## 5.5 CONSIDERATIONS IN THE DESIGN OF SIGNED SHARED LANES

Several of the cases involved roadways with signs that stated bicyclists have rights to occupy a travel lane but did not have painted lanes or sharrows. The NACTO (2014) and AASHTO (2012) guidelines include discussion of signed lanes, but these sections focus mainly on the use of signage to designate bicycle boulevards or routes and wayfinding. The AASHTO (2012) guidelines note that signs do not alter the geometric design or traffic speeds on roadways and thus are unlikely to reduce crashes. The AASHTO guidelines also state that the cluttered nature of urban roadsides reduces the effectiveness of signs and that markings are a better notification for drivers.

Our results indicate drivers on signed, shared lanes without markings are likely to encroach into existing lanes, pass, or queue behind cyclists (Table 4-4). Among all cases, the rates of queuing on signed, shared lanes ranged from 55% to 81%. The regression results indicate that, in terms of behaviors during interactions with bicyclists, drivers on roadways with signed, shared lanes, narrow shoulders, or only striped center lines do not differ significantly from drivers on roadways with no facilities. With respect to procedures in the HCM for estimating LOS, the findings indicate the need to account for bicyclists and interactions with vehicles and, as with sharrows, PCEs of one or more may be warranted. Although additional study is warranted, PCEs for roadways with signed shared lanes, narrow shoulders, or no facilities may be greater than for roadways marked with sharrows.

## 5.6 CONCLUSIONS

NACTO (2014) and AASHTO (2012) guidelines identify the relative advantages and disadvantages of buffered bicycle lanes, striped bicycle lanes, sharrows, and other types of facilities. Field observations of bicycle-vehicle interactions at nine locations in Minnesota provide additional evidence about the correlations between driver behaviors when interacting with bicyclists on different types of roadways with different types of facilities. The results confirm that driver behavior is more predictable and that drivers are more likely to remain in their lanes when interacting on roadways with buffered or striped bicycle lanes than on roadways with sharrows, other types of bicycle facilities, or no facilities. Although descriptive results indicate that driver behavior on roadways with sharrows may be more predictable than on roadways with no facilities, the model’s results are inconclusive and show no significant differences between driver behaviors on roadways with sharrows and roads with no facilities. The modeling results also indicate that there are no significant differences in driver behaviors when interacting with cyclists on roadways with signed shared lanes, narrow shoulders, or only center striped lanes.

These results have several implications for design. Given an objective of increasing predictability of driver behavior, buffered or striped bicycle lanes offer advantages over other types of facilities where space and resources allow. Whether sharrows are associated with more consistent driver behaviors during interactions with cyclists may depend on site-specific circumstances. Although sharrows may alert drivers to the potential presence of cyclists, traffic impacts on roadways with sharrows may not differ significantly from roadways with no facilities. Signs indicating the presence of bicyclists also may alert drivers to the potential presence of cyclists, but there is no evidence from the cases in this study that interactions on roadways marked only with signs differ from roadways with no facilities. Thus, from the perspective of increasing reducing potential traffic impacts such as queuing behind cyclists, bicycle lanes are to be preferred over sharrows or signage.

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